

Workshop Summary Space Environmental Effects

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This report summarizes the workshop held on Space Environmental Effects that was held as a part of SPRAT XI. Approximately 30 people attended the workshop. The underlying concern of this group was related to the question of how well do laboratory tests correlate with actual experience in space. The discussion ranged over topics pertaining to tests involving radiation, atomic oxygen, high voltage plasmas, contamination in LEO, and new environmental effects that may have to be considered on arrays used for planetary surface power systems.

Most Important Concerns

There is always a concern over radiation testing. Although the 1 MeV equivalent electron fluence concept together with its related damage coefficients has been in use for several years for predicting the behavior of silicon solar cell arrays, there is still controversy as to how accurate these predictions are. It has always been difficult to check the accuracy of prediction vs experience for several reasons. First, most predictions involve using the published models of the trapped van Allen belts, and these models may only be accurate to within an order of magnitude. Indeed, it may be effectively argued that it is not worth the expenditure of a great deal of effort in deriving extremely accurate damage coefficients, since the models of the radiation belts, or perhaps the radiation belts themselves, are so uncertain. Second, it is often difficult to get data on the short circuit current or maximum power on spacecraft arrays because this data is not available in pure form. Rather, it is usually derived indirectly from other data that is telemetered. Third, there may be other effects which also degrade panel performance that cannot be separated from the radiation effects. They include the effect of uv degradation of coverglasses and/or adhesives, the effect of high panel temperatures which may anneal the panel, the effect of contamination which may arise from outgassing of spacecraft components, rocket plumes, products of atomic oxygen erosion, etc. Fourth, the data available from solar cell flight experiments is usually plagued by one or more of the above effects and the data may be misleading.

In spite of the concerns, real or imagined, the damage coefficient/1 MeV equivalent fluence concept appears to be useful. It is relatively easy to apply and the software for its use is widely distributed so that different panel designers can compute radiation degradation in the same way. Radiation experiments sufficient to allow the computation of a new set of damage coefficients for GaAs/Ge cells have been recently completed at JPL, and these data will be disseminated in the near future.

There are other areas of concern having to do with applying laboratory radiation damage tests to spacecraft panels. One example is a rate effect problem. Do the low flux rates actually seen in space

allow time for self annealing that is not seen in accelerated ground tests? All ground testing is done at accelerated rates. Some attempts have been made to see whether there is a rate effect problem. For example, recent rate tests at JPL using electrons incident on GaAs/Ge cells used two different flux rates differing by a factor of 80. No difference in the cell output was observed, but the "slow" irradiation only lasted a total of 24 hours, much less than the exposure time would be in space for most orbits. Rate tests using protons have not been done to our knowledge. Since one could legitimately expect any possible rate effect to be dependent on the incident particle type, and possibly its energy, a great deal of additional testing will be necessary to effectively address this problem. Rate effects may be process and contamination dependent (LPE vs MOCVD for example) because the impurities introduced during processing may influence the types of radiation defects produced.

Other areas of concern discussed had to do with bias, illumination, and cell loading during ground test radiation experiments. It is not believed that GaAs or Silicon cells are affected by illumination or loading, but the radiation degradation of InP cells is known to be dependent on illumination, so a cautionary flag is raised for those who will be irradiating cells made from new materials.

The irradiation of solar cell areas which are incompletely protected by their coverglasses. These areas are usually near the busbar, but they may also occur when a coverglass develops a crack during panel assembly. In silicon cells, such exposed areas near the busbar have been found to be especially vulnerable to low energy protons. Some preliminary data indicates that the busbar area of GaAs cells are also vulnerable to low energy protons and the busbar itself should have enough thickness to stop most of the low energy protons expected for its particular environment. Cracks in coverglasses do not seem to present a serious problem if the coverglass adhesive at the bottom of the crack is intact (this is usually the case). Another related area of concern is the edge of the solar cell which may not be shielded to obliquely incident radiation. There is very little data dealing with irradiated solar cell edges.

The effect of atomic oxygen on solar panels in LEO is of great concern. The interconnects and flexible substrates are particularly vulnerable, and methods of protecting these items are under development. For instance a coating of SiO_x has been developed for protecting kapton substrates and gold plating on interconnects seems to give some protection. Adequate ground tests need to be developed for proving these developments. Testing by chemical methods may be a possibility, but there must be a correlation between the tests used and actual experience in space.

The development of high voltage arrays is seen to be very desirable in some cases. The decrease in conductor size allowed will provide a significant decrease in array mass in very large arrays. The high voltages bring forth problems with arcing caused by the interaction of the solar arrays with the space plasma. The experience of the workshop participants seemed to indicate that arcing was probably not a hazard to silicon solar cells, but GaAs cells could be a problem due to their greater susceptibility to reverse bias (GaAs/Ge cells do not seem to show this increased susceptibility). There is also a definite hazard to the spacecraft electronics. Here again, the question is raised as to the effectiveness of ground testing. Tests are typically made with monoenergetic particles normally incident. Correlation with such tests with in-flight experience is minimal. Well designed, fully instrumented flight experiments need to be flown.

A rather interesting discussion developed around the requirements specified in Qualification Testing of solar panel components. Many of these tests are performed to certain levels because "that's the way its always been done." These test levels are not likely to change unless they are driven by costs. That is, if a new solar cell design cannot pass an exceptionally high test level, and an expensive development program would have to be launched to develop a cell which could pass the test, a project manager may modify the levels to reflect a more realistic test. Tests applied to new materials may not

be appropriate, but may be borrowed from tests on other materials. New tests may have to be developed for new materials. For example, the greater susceptibility of GaAs solar cells to reverse bias conditions has prompted the requirement that these cells pass certain reverse bias stress tests. Such tests were not necessary for silicon cells. There is always a desire to develop a set of uniform test standards to apply to all spacecraft and their components. But these tests are necessarily mission dependent, driven by the particular environment to be experienced by that mission, and the dream of uniform test standards is doomed to remain but a dream.

Array Lifetimes and Operation in the Van Allen Belts

Desirable array lifetimes vary greatly with the mission. Communications satellites operating at GEO need to have lifetimes of 15 years or greater. But an array lifetime of 20 years for SpaceLab in LEO is desirable. However the lifetime of the spacecraft is not usually controlled by the lifetime of the solar arrays. Other elements usually give up first, for example the batteries, station keeping fuel, etc. Array contamination may be a concern for long duration missions. Possible contamination sources noted were products arising from atomic oxygen sputtering, chemical reaction products, and contamination products from electrostatic discharges which may collect on the arrays.

The question of can arrays operate in the van Allen belts can be answered by "yes, they can." Arrays are suitable power sources for most areas in the van Allen belts, but there are certainly some areas where most present-day arrays cannot stay for more than a few days or even hours without losing a significant amount of their power. But arrays can be designed to operate even in the most intense region of the belts for limited periods of time. Such arrays are likely to laden with a large mass of shielding, both front and rear, for the solar cells.

Lightweight array designs are currently under evaluation for the purpose of producing power for ion propulsion engines. These spacecraft are expected to start at LEO and spiral up through the van Allen belts over a period of 100-200 days. It is typical for these arrays, based on conventional thin crystalline silicon cells, to lose $\approx 70\%$ of their power after one trip. Future arrays for operating in these intense radiation environments may use thin film solar cells made of (hopefully) radiation resistant materials such as amorphous silicon, copper indium diselenide, indium phosphide, cadmium telluride, etc. Other solutions are in-orbit annealing and the use of concentrator arrays, where self-shielding would help.

Approaches to Shielding

The workshop participants did not hold a great deal of hope for new shielding methods. The use of integral covers, whether deposited by electrostatic bonding or sputtering, could enable the solar array to operate at high temperatures for annealing purposes. Boeing has developed an integral coverglass/solar cell system that can operate at 500°C for ≈ 60 seconds. The next step is to develop a method of raising the spacecraft solar panels to that temperature in a practical manner.

Planetary Surface Power Systems

Damage to solar arrays from dust accretion and scratches from cleaning and/or wind blown objects was mentioned. Earth experience is useful but may be benign compared to other surface

environments. High voltage arrays in Mars' low density atmosphere might experience Paschen breakdown. Likewise, "plasma puffs" in space or Lunar environments (from venting, propellants, etc.) could precipitate discharges.

Conclusion

The discussions in the Space Environmental Effects Workshop were spirited and useful. Of particular importance was the participation by array people who introduced a "reality factor" and raised some pointed questions. The broad representation of the solar cell community in these workshops assures both continuity and vitality. While many of the questions raised in the workshop were not answered, the discussions indicated that people were addressing most of the problems and that answers were available.

JOURNEY INTO TOMORROW - NASA's FUTURE SPACE POWER REQUIREMENTS

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With the President's Space Exploration Initiative (SEI) of returning to the Moon and then going to Mars, NASA will need to develop a number of enabling technologies, chief among them being power for spacecraft and surface bases. The SEI power technology program will build upon ongoing efforts in the areas of advanced photovoltaics, energy storage, power management, nuclear power, and higher conversion efficiency systems.

INTRODUCTION

The Office of Aeronautics, Exploration and Technology (OAET) of the National Aeronautics and Space Administration (NASA) sponsors the agency's basic technology programs in aeronautics and space research, including space energy conversion research and technology (R&T). The principal objective of the space energy conversion R&T program is to provide the technology base to meet the power system requirements for future space missions, including growth Space Station, Earth orbiting spacecraft, lunar and planetary bases, and solar system exploration. The space power program is included in three separate but interrelated parts of the space R&T program: R&T Base, Civil Space Technology Initiative (CSTI) and the Exploration Technology Program (ETP). The power program is divided as follows among the three technology programs (Bennett 1991a):

R&T Base

- Photovoltaic Energy Conversion
- Chemical Energy Conversion
- Thermal Energy Conversion
- Power Management
- Thermal Management

Civil Space Technology Initiative

- High Capacity Power

Exploration Technology Program

- Surface Solar Power
- SP-100 Space Nuclear Reactor Power System

Recent studies of spacecraft such as the Tracking and Data Relay Satellite System (TDRSS) and the Earth Observing System (EOS) (see Figure 1) have shown that the electric power system (EPS) can be on the order of 25% of the mass of the spacecraft, with the EPS mass almost evenly divided between the source (photovoltaics), storage, and power management and distribution (PMAD) (see Figure 2). Thus, there is an incentive to reduce the mass of the EPS since a factor of two reduction in the mass of the EPS could translate into a factor of two increase in the mass fraction allocated to the payload (or more power could be produced for the same mass fraction) (Brandhorst 1991 and Kenny et al. 1990). Reducing mass is crucial to the eventual exploration of the Moon and Mars because the mass that must be launched into low-Earth orbit (LEO) directly affects the cost of mission operations (Mankins and Buoni 1990).

SPACE EXPLORATION INITIATIVE

Power has been given an even bigger boost by the new national space policy which includes the goal of expanding human presence and activity beyond Earth orbit into the solar system (White House 1989). Clearly with the national goal of moving outward in space and the ever increasing demands of more sophisticated spacecraft, power becomes a very critical technology - and for the inner solar system that generally means solar-based power.

In implementing the national space policy the President has called for the completion of Space Station Freedom (SSF), the return to the Moon (this time to stay), and manned missions to Mars as part of a new Space Exploration Initiative (SEI). As Arnold D. Aldrich, NASA's Associate Administrator for Aeronautics, Exploration and Technology stated in a speech on the SEI in Huntsville, Alabama on 26 September 1990:

"The essence of SEI is not a future program plan nor a current political agenda. The essence is simply an idea: that men and women will return to the Moon and then will explore the planet Mars. Startling in its simplicity, profound in its consequence, the idea of SEI is so powerful given the reach of our space technology capability, that it cannot be ignored. It is an idea whose time has arrived."

Basically what SEI is is a long-term goal or strategic horizon or "vision" for the civil space program that can be used to guide the space program and to provide a basis for measuring progress in the space program.

The reasons for going to the Moon first include its nearness and partial gravity which allows humans to learn to build, to live, and to work on a new planetary surface that is close enough to Earth (~3 days) for emergency returns. In addition the Moon offers the potential for new science opportunities including a location for astronomical observatories. Overall, the Moon provides an evolutionary approach to expanding human presence and activity.

The reasons for going to Mars are many, including:

- To fulfill the human imperative to explore
- To increase knowledge of the solar system, the galaxies, and life itself
- To bind nations together in a peaceful, common endeavor
- To improve the quality of life
- To strengthen our country's competitive economic position

Figure 3 provides an overview of the Space Exploration Initiative by placing it in context of previous studies and the near-term planning and study activities which must precede any decision to go back to the Moon or to go to Mars. Within the philosophy of SEI is the idea of doing mission studies and technology development before a decision is made on the architecture to be used for the lunar/Mars initiative. No technology selections have been made yet. To complement Figure 3, Figure 4 shows selected recent SEI milestones and illustrates the recent history and progress of the SEI program.

One of the recent activities related to SEI has been the Synthesis Group evolution of alternative architectures for the lunar/Mars missions. Basically, the Synthesis Group, which is an outgrowth of the Vice President's request that a wide net be cast for innovative ideas, has developed four architectures. Their work has noted that a key to the successful achievement of the goals of SEI is plentiful power at a reasonable cost. Power will be needed for spacecraft, for planetary bases on the Moon and Mars, for mobile surface vehicles, and for propulsion (such as electric propulsion) (Buden et al. 1991). This conclusion is in concert with other studies on SEI (NASA 1989 and NRC 1990).

The Synthesis Group has concluded that multiple power units and types will be needed to meet the wide range of requirements for the different mission phases. The preference of the Synthesis Group is for modular units to minimize the need for assembly in space and to provide redundancy and a growth capability. The Synthesis Group has recognized that power development will be a continuing effort with product improvements introduced as model or block changes. One obvious but very important conclusion is that emergency life support power systems that are highly reliable (>0.995) will be needed to back up other life support power systems. One of the key challenges will be providing power during the long (14-Earth-day) lunar night. Some of the possible power requirements identified by the Synthesis Group include (Buden et al. 1991):

Surface Vehicles	<10 kWe to <100 kWe
Piloted spacecraft	~5 kWe to ~50 kWe
Mars Cargo Vehicle	~10 kWe
Lunar/Mars Habitats	~30 kWe to ~100 kWe
Lunar Settlement	~1 MWe or more
Mars Cargo Vehicle (Electric Propulsion)	~10 MWe
Piloted Mars Vehicle (Electric Propulsion)	≤ 100 MWe

Figure 5 taken from NASA's 90-day study of SEI shows the lunar surface power system options and how the power system might evolve. Clearly the initial installations will be powered by photovoltaic arrays with chemical energy storage. As power demands rise, nuclear power (i.e., nuclear reactors) will be the logical choice because of their ability to operate through the long lunar night. Figure 6 compares the total system mass for a photovoltaic array/regenerative fuel cell (RFC) system and a nuclear reactor power system for the provision of 100 kWe continuously through the lunar day and night. Figure 7 shows a possible lunar outpost arrangement. Regardless of how the power system evolves there will be a clear need for solar-based power either initially as the base is established or later as backup to the nuclear reactor power system (NASA 1989).

EXPLORATION TECHNOLOGY PROGRAM

In recognition of the need to develop technologies in several areas before proceeding with a specific architecture NASA has established the Exploration Technology Program. This program along with human support (life sciences research), the national launch system (heavy-lift launch vehicle), robotic missions, and Space Station Freedom are prerequisites for human exploration of the Moon and Mars.

The Exploration Technology Program has been established (1) to increase reliability and reduce risk; (2) to reduce developmental and operational costs; and (3) to enable new and innovative capabilities in the areas of

- Space Transportation
- In-space Operations
- Surface Operations
- Human Support
- Lunar and Mars Science
- Nuclear Propulsion
- Information Systems and Automation

Figure 8 shows the structure of the SEI technology and advanced development programs. Note that power is involved in several programs (Mankins and Buoni 1990).

Within the Surface Operations area is the Surface Solar Power Program whose objective is to develop solar-based power technology to a level of readiness sufficient to enable or enhance extraterrestrial surface missions. The objective is planned to be achieved through advancing the technologies of energy storage by means of regenerative fuel cells, power generation by means of photovoltaic arrays and advanced, low mass reliable electrical and thermal power management subsystems. The goal is to achieve a solar-based surface power system design based on advanced technologies in these four subsystems that has a reliable life in excess of 40,000 hours at a specific power of 3 We/kg for lunar applications and 8 We/kg for Martian applications. The emphasis will be on higher efficiency, lighter weight solar arrays with a goal of 300 We/kg; high energy density chemical energy storage systems with a goal of 1000 We-h/kg; and automated, smart, fault-tolerant PMAD subsystems (≤ 55 kg/kWe) (Bennett 1991b).

Also within the Surface Operations area is the SP-100 Space Nuclear Reactor Power System Program whose objective is to develop and validate the technology for space nuclear reactor power systems that can produce tens to hundreds of kilowatts of electric power and be capable of seven years of operational life at full power. The SP-100 program is a joint endeavor of NASA, the Department of Energy (DOE) and the Strategic Defense Initiative Organization (SDIO). Under the SP-100 program a generic 100-kWe space reactor power system is being designed. The reactor concept will be scalable from 10 kWe to 1000 kWe. SP-100 provides a technology base for nuclear electric propulsion (NEP) missions to the outer planets, surface power and spacecraft power (Pluta et al. 1989).

One very important area requiring power is the Mars transportation system. Figure 9 shows the various Mars transportation options. All of these spacecraft are going to require power for the ~400-day to ~1000-day round-trip missions to Mars. One of the options, solar electric propulsion (SEP), is very dependent on having very light-weight and very low cost space solar arrays.

ROBOTIC MISSIONS

As part of SEI there will be a number of precursor robotic missions which will advance our scientific understanding and develop the basis for human science exploration. These robotic explorers will determine suitable/desirable landing and outpost sites as well as providing design data for human mission elements and demonstrating the technologies and operational concepts for the follow-on human missions. Consequently these robotic missions are integral to the SEI and they represent opportunities and challenges for spacecraft power system designers. For the Moon the emphasis will be on selecting the landing/outpost site. The principal lunar robotic mission is planned to be the planned Lunar Observer which will study the Moon from a 100-km polar orbit.

For Mars the emphasis will be on science and ensuring the success of the follow-on human missions. Some of the candidate Mars robotic missions include: Mars Observer, Site Reconnaissance Orbiter, Mars Landers, and Mars Sample Return/Rovers. The Mars Observer is currently being prepared for a 1992 launch. Figure 10 shows one possible Mars robotic rover concept. While this particular rover has radioisotope thermoelectric generators (RTGs) for power, studies at NASA's Lewis Research Center (LeRC) have shown that solar-powered rovers can be operated on Mars (Appelbaum and Flood 1989).

Figure 11 shows the initial listing of missions developed by NASA's Office of Space Science and Applications ((OSSA). Currently NASA/OSSA is preparing a long-range strategic plan for missions involving astrophysics, solar system exploration, Earth science, space physics, communications, life science and microgravity research. Two of the key technologies identified by NASA/OSSA that are of interest to the Space Photovoltaic Research and Technology (SPRAT) Conference are solar arrays and solar cells. In addition there is a need for radiation hard parts and detectors. Clearly radiation-resistant solar cells mounted on light-weight arrays would be of great benefit to the space science community.

NEAR-TERM ACTIVITIES

Currently NASA is responding to the *Report of the Advisory Committee on the Future of the U. S. Space Program* which supports the eventual lunar/Mars missions and advocates increased support for technology development (Advisory Committee 1991). NASA will take the results of the Synthesis Group study and integrate them into the overall planning for SEI, which includes defining and executing an SEI preparatory program that includes meaningful technical analyses. In carrying out the SEI program NASA will be working closely with other Federal agencies including the Department of Defense and the Department of Energy. Basically NASA will be nurturing the concept and developing program options for the eventual national decisions.

CONCLUSION

NASA's future space programs will be heavily dependent upon power. As a consequence the space power community should look upon the requirements of the civil space program as an exciting technical challenge to advance the state of the art through developing electric power systems with higher efficiencies, reduced masses, improved reliability, longer lifetimes and reduced costs.

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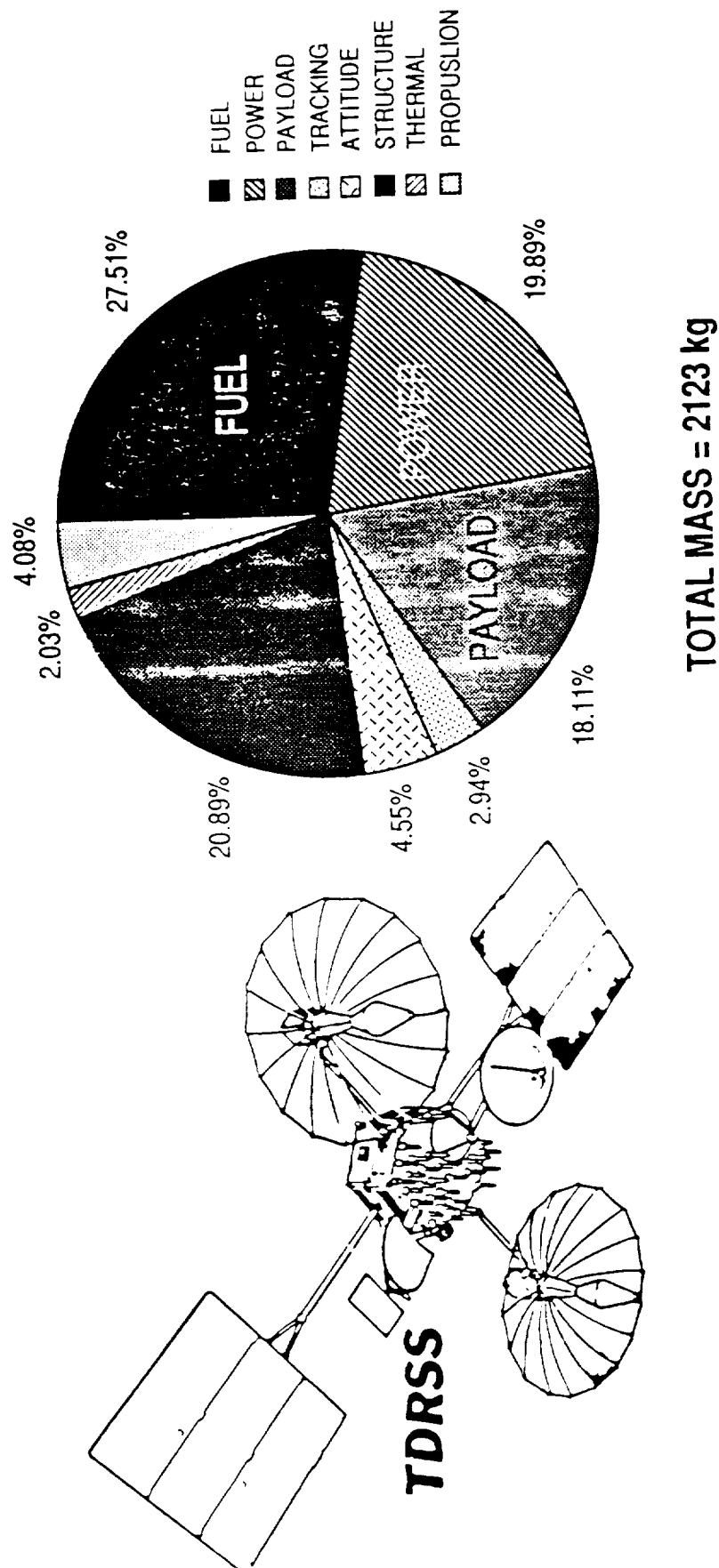
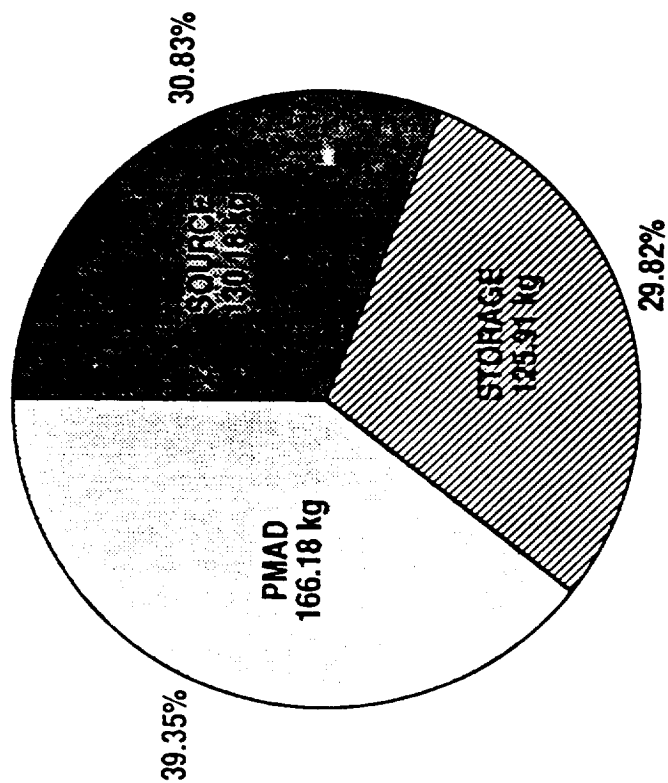
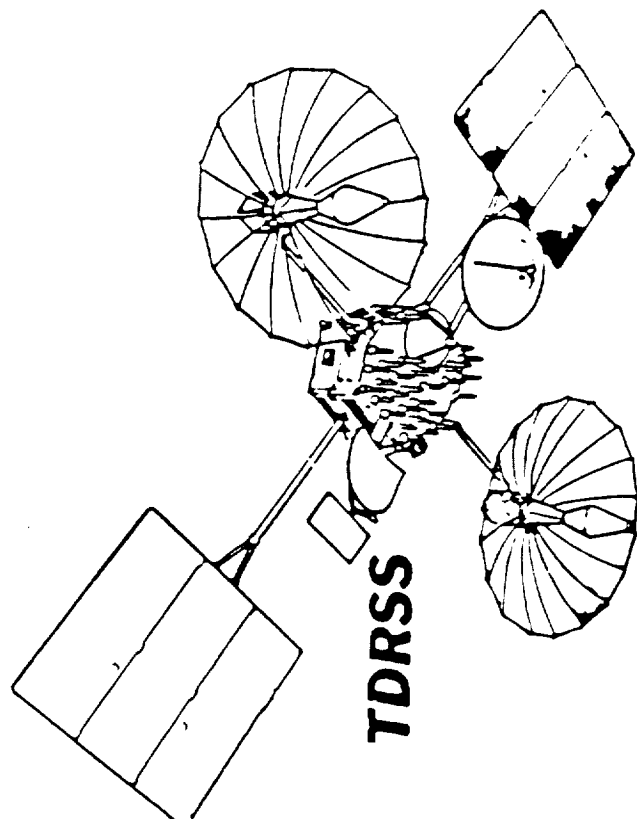


Figure 1. Distribution of the Wet Mass of the Tracking and Data Relay Satellite System (TDRSS).



TOTAL EPS MASS = 422kg

Figure 2. Distribution of the Masses of the Subsystems of the Electric Power System (EPS) of the Tracking and Data Relay Satellite System (TDRSS).

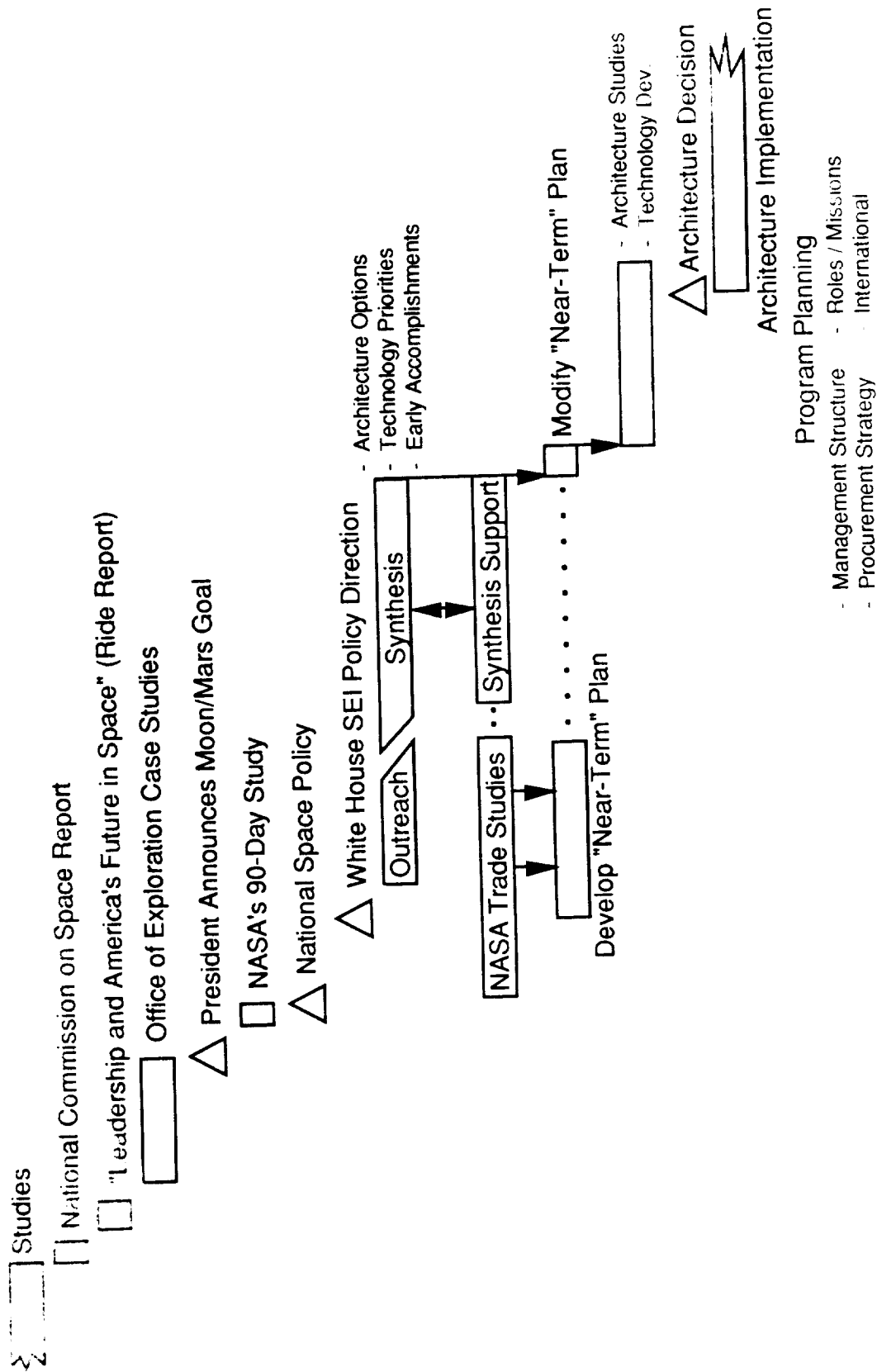


Figure 3. Overview of the Space Exploration Initiative (SEI).

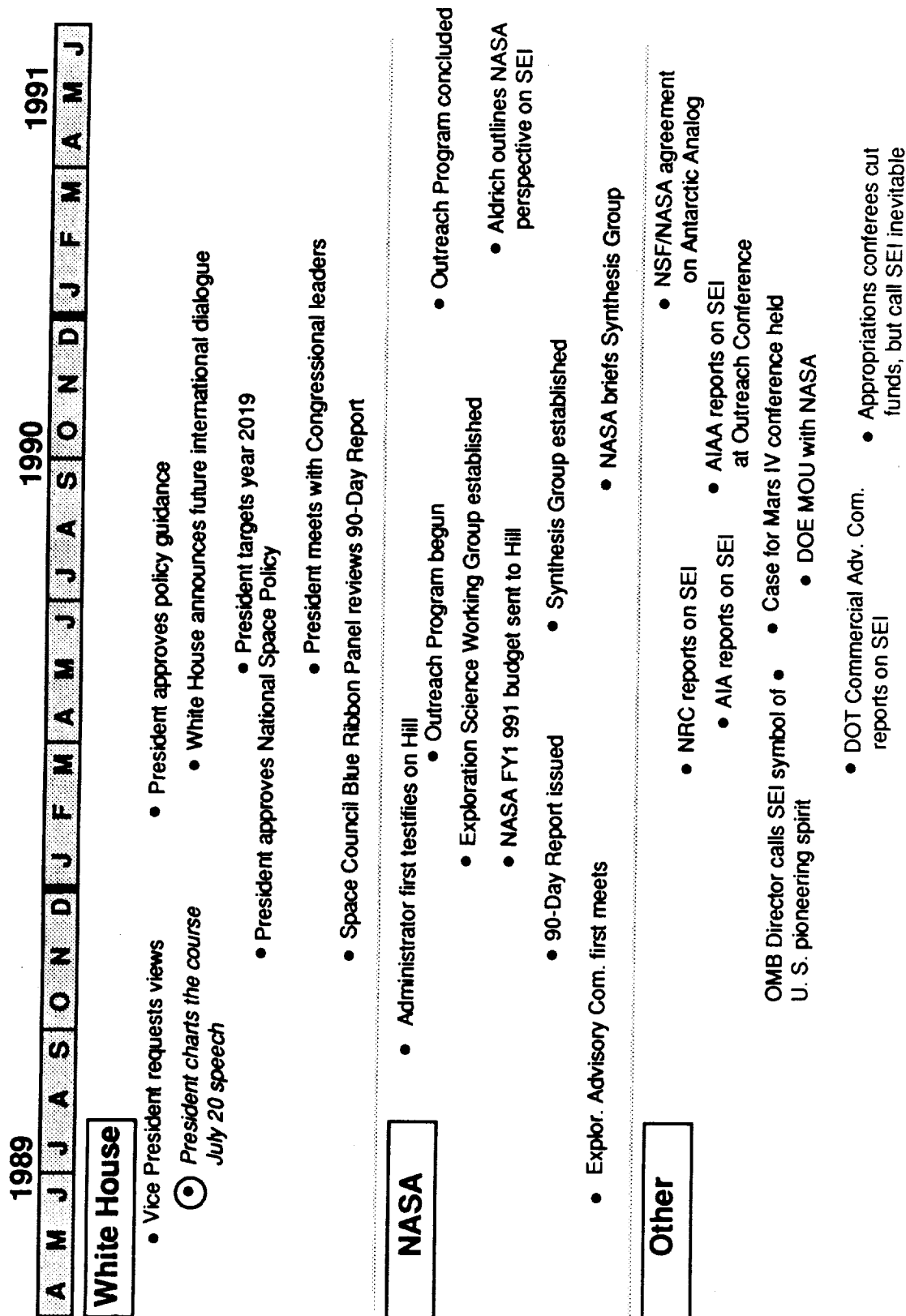


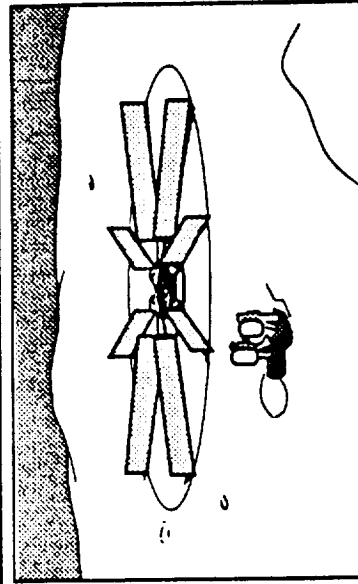
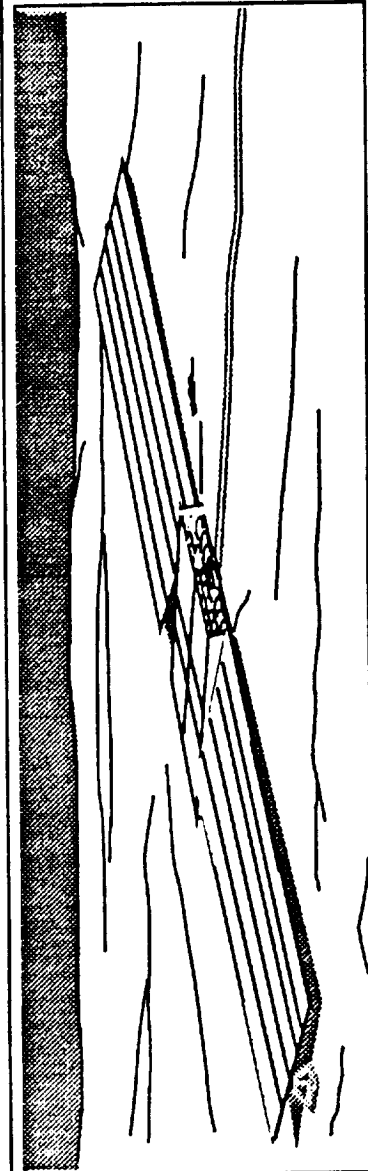
Figure 4. Selected Milestones for the Space Exploration Initiative (SEI).

Lunar Surface Power System Options

Strategy: Early Outpost Power Needs



Later Outpost Power Needs



• Power Generation

- Photovoltaic Arrays or Solar Dynamic Modules
- Low-Moderate Mass/kW
- Near Term Development
- Can Be Located Near Outpost
- Ease of Deployment

- Daytime Power Only
- Power Storage Required
- Moderate Spares
- Moderate Crew Support

• Power Storage

- Batteries
- Near Term Development

- High Initial Mass/kW
- Short Lived Systems

- Regenerative Fuel Cells
- Longer Term Development
- Moderate Mass/kW
- Short Lived Systems
- High Spares/Resupply

• Nuclear Power

- Continuous Day/Night Power
- No Power Storage Required
- Low Initial Mass/kW
- Lowest Spares/Resupply
- Long Life Systems
- Minimum Crew Support
- Longer Term Development
- Must Be Remote to Outpost
- Radiation Shielding
- Political

Figure 5. Options for the Lunar Surface Power System.

**Example:
Systems to Provide 100 kW
Continuous Day/Night Power**

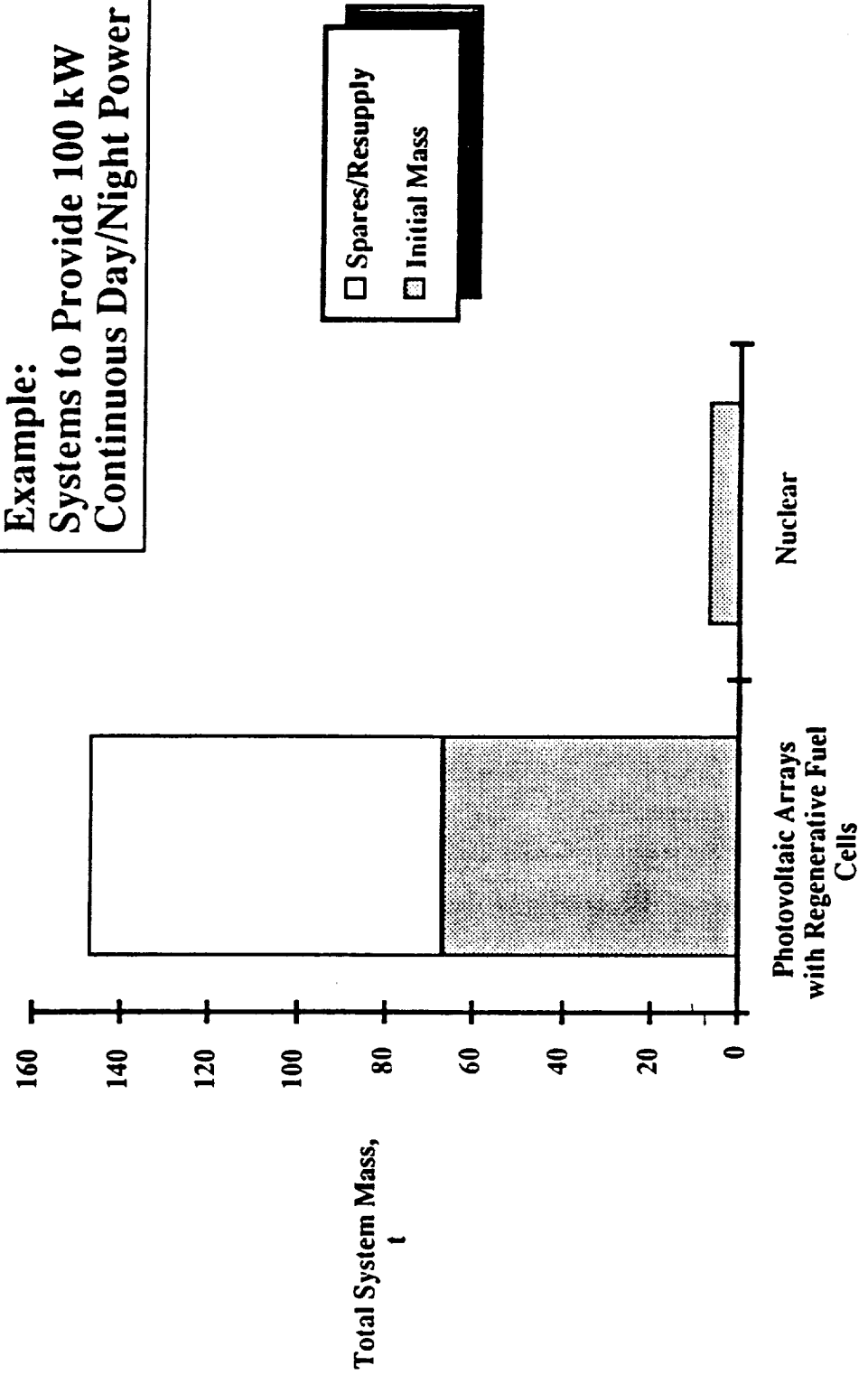


Figure 6. Comparison of the Masses for Two Lunar Surface Power System Options (assuming a 10-year life).

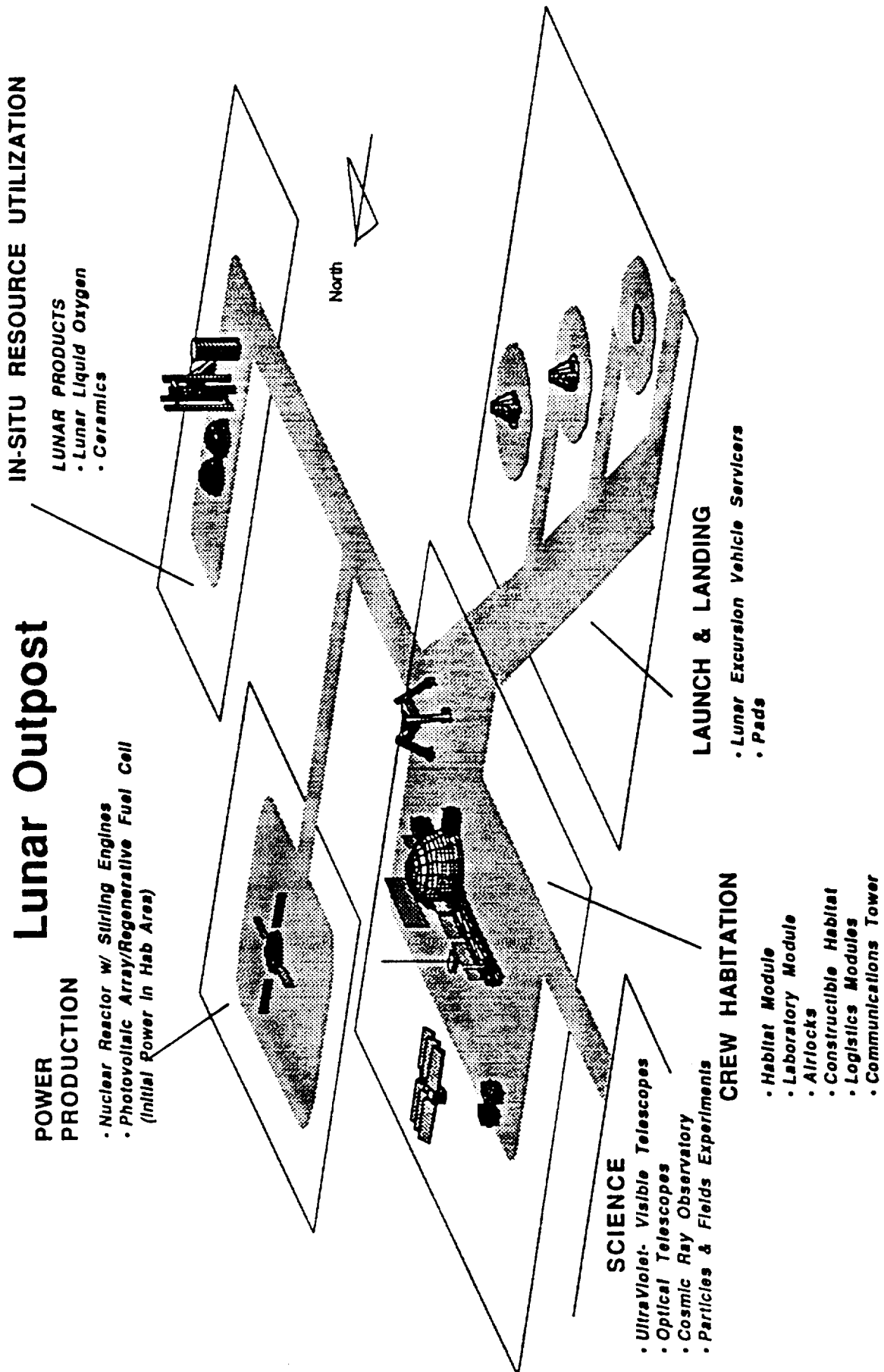


Figure 7. A Possible Layout for the Lunar Outpost.

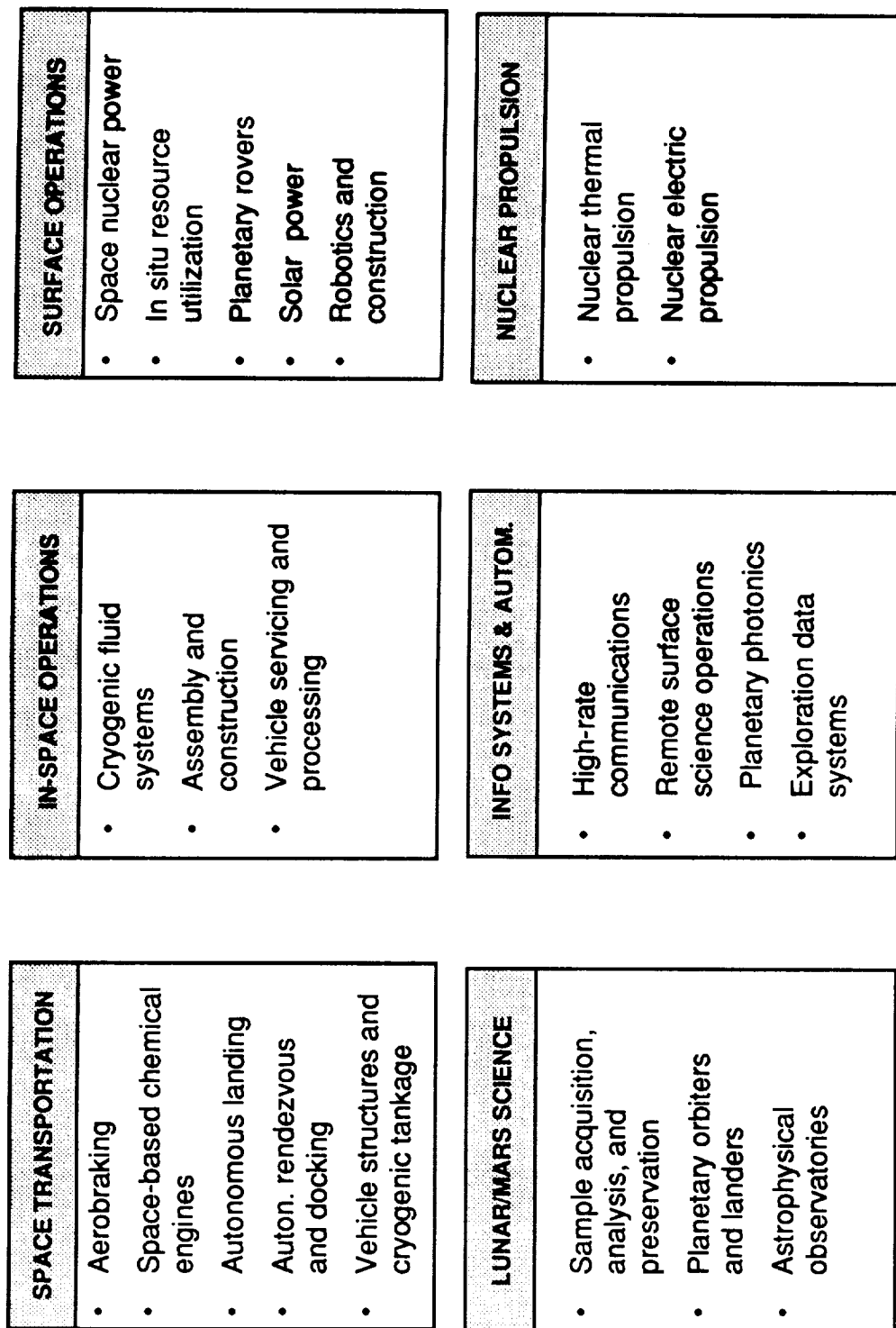


Figure 8. Organization of the Space Exploration Initiative Technology and Advanced Development Programs.

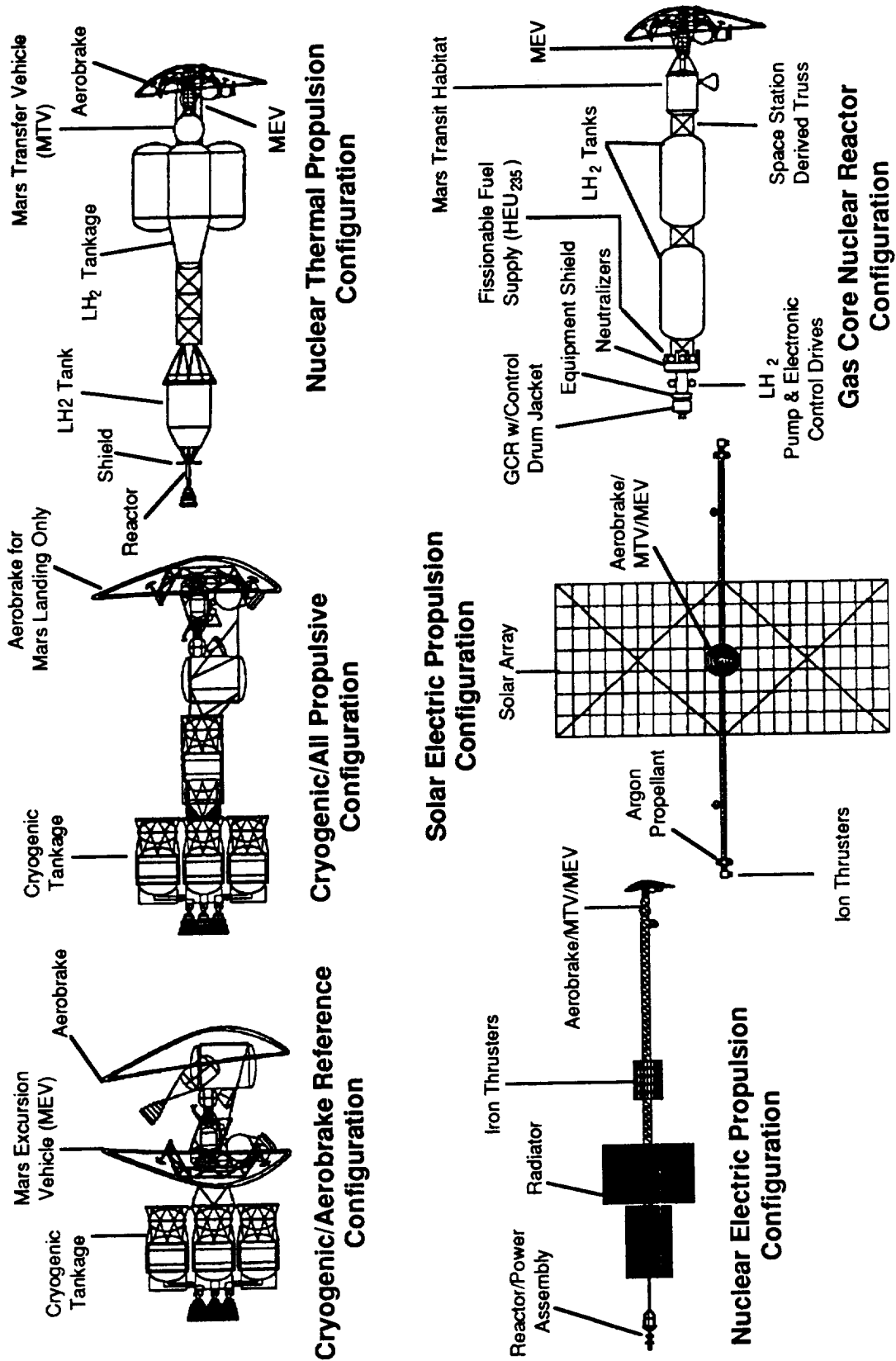


Figure 9. Concepts for Mars Transportation Vehicles.

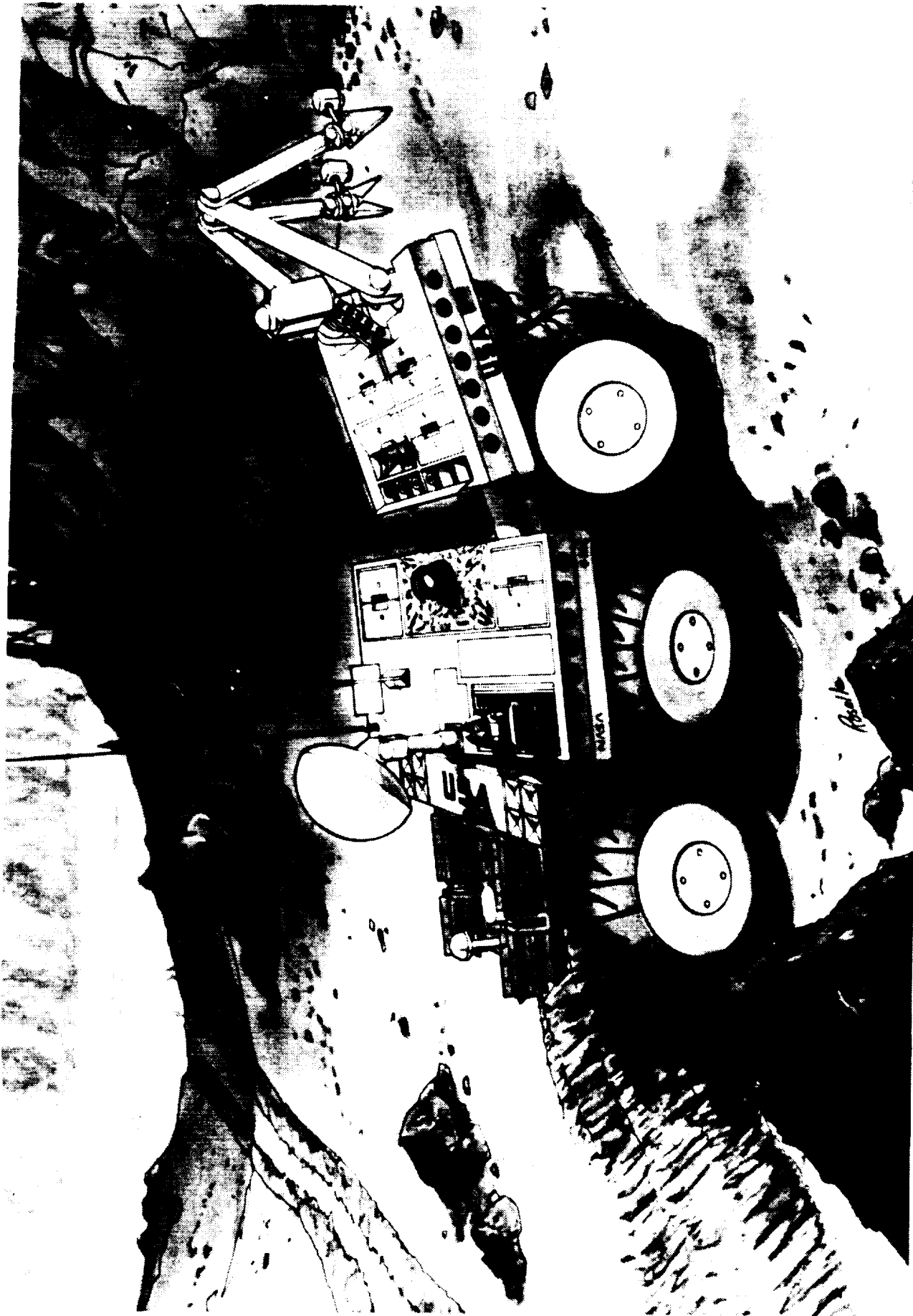


Figure 10. Concept for a Mars Robotic Rover.

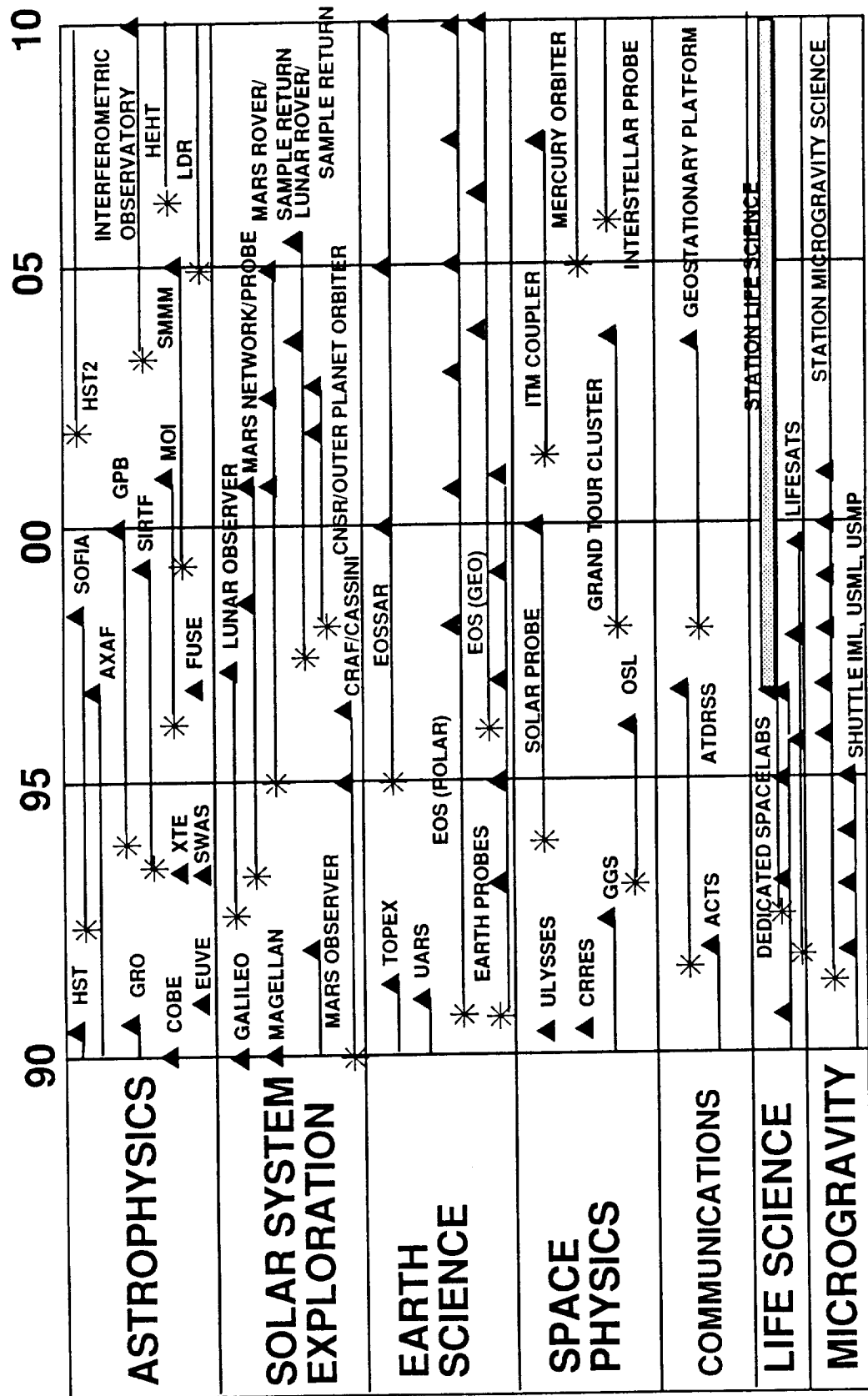


Figure 11. Preliminary Mission Model for NASA Space Science Missions.

THE SURVIVABLE POWER SUBSYSTEM DEMONSTRATION PROGRAM (SUPER)

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OVERVIEW

- **OBJECTIVE**
- **BACKGROUND**
- **OVERVIEW OF DESIGN FEATURES**
- **LOW POWER INITIATIVE**
- **CONCLUSIONS**

SUPER PROGRAM OBJECTIVE

**DEVELOP AND DEMONSTRATE A POWER SUBSYSTEM
WHICH WILL SURVIVE POTENTIAL MILITARY THREATS
AND BE PRACTICAL ENOUGH THAT SATELLITE
PROGRAMS WILL USE IT**

SUPER REQUIREMENTS

SURVIVABILITY

PRACTICALITY

WEIGHT

SAFETY

PRODUCTION COST

ORBITAL FLEXIBILITY

RELIABILITY

PACKAGING FLEXIBILITY

SUPPORTABILITY

SCALEABILITY

LAUNCH ENVIRONMENTS

TECHNOLOGY BREAKTHROUGHS

CONCENTRATOR ELEMENT WEIGHT

SOLAR CELL EFFICIENCY, TEMPERATURE THRESHOLD

POWER SUBSYSTEM AUTONOMY

FULL SCALE CONCENTRATOR ARRAY POINTING AND TRACKING DESIGN

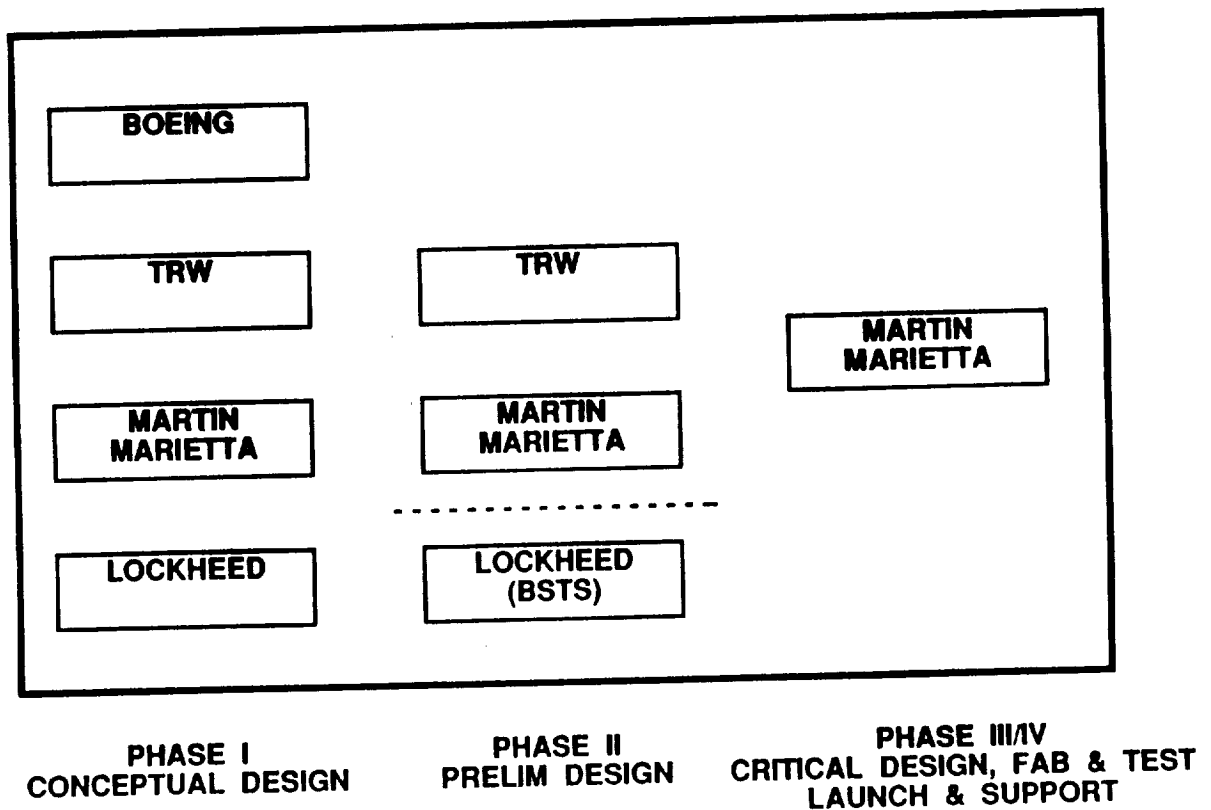
MULTIPLE DEPLOYMENT AND RETRACTION ARRAY

LARGE C-C STRUCTURAL PART PRODUCTION

GaAs BYPASS DIODES

LOW LOSS BATTERY BYPASS CIRCUIT

THE SUPER HORSE RACE



OVERVIEW OF DESIGN FEATURES

- **MARTIN MARIETTA CONCENTRATOR APPROACH
(GENERIC SUPER INTEGRATED SUBSYSTEM)**

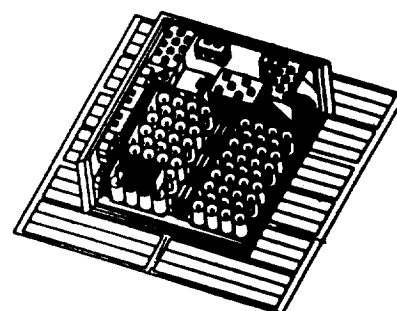
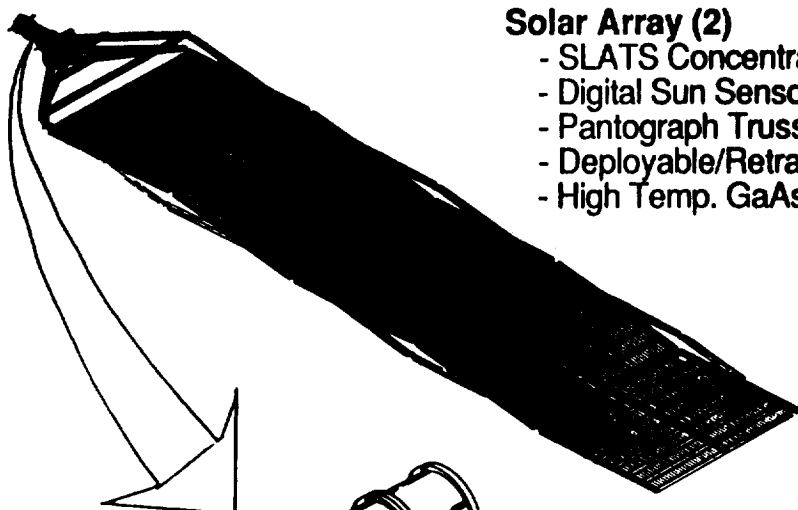
OVERVIEW OF DESIGN FEATURES (PDR GENERIC APPROACH)

- **INTEGRATED POWER SUBSYSTEM**
 - **SOLAR ARRAY**
 - **DEPLOYMENT, RETRACTION, AND TRACKING MECHANISMS**
 - **POWER MANAGEMENT AND DISTRIBUTION**
 - **THERMAL MANAGMENT**
- **SURVIVABLE**
 - **ENABLING TECHNOLOGY:
PRE-SUPER STATE-OF-THE-ART SOLAR SYSTEMS
COULD NOT SURVIVE**
 - **ACTIVE AND PASSIVE FEATURES**
- **MODULAR AND SCALEABLE THROUGHOUT 2KW - 40KW USER RANGE**

SUPER KEY ASSEMBLIES

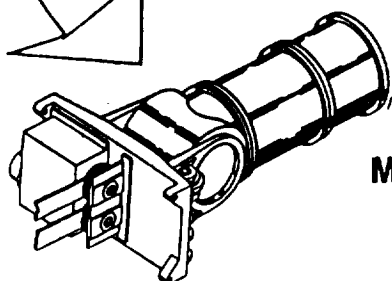
Solar Array (2)

- SLATS Concentrator
- Digital Sun Sensors
- Pantograph Truss
- Deployable/Retractable
- High Temp. GaAs Cells



Modular Power Assembly (2)

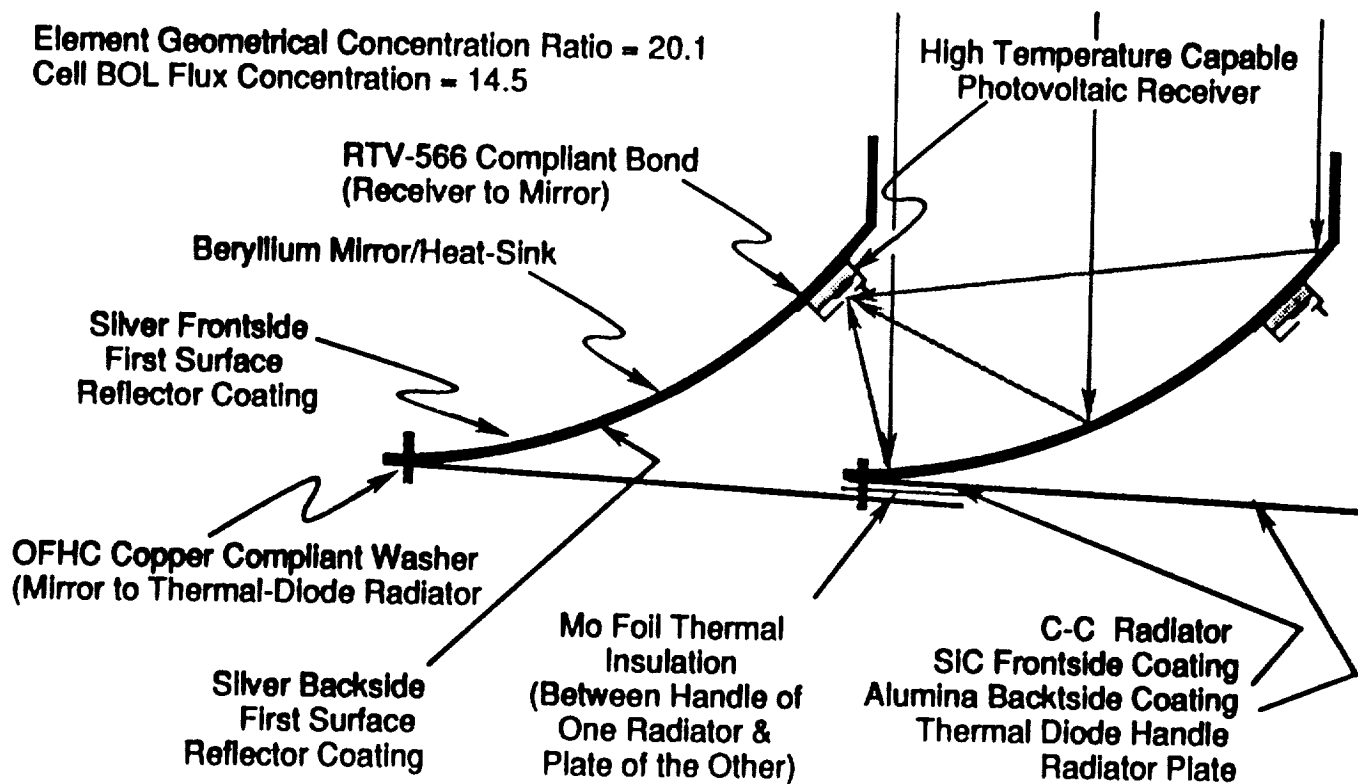
- 50 AH IPV NiH2 Cells
- Individual Battery Maintenance
- Shunt Regulated Array
- Processor Control
- WCHP Thermal Management
- Multi-Threat Shield



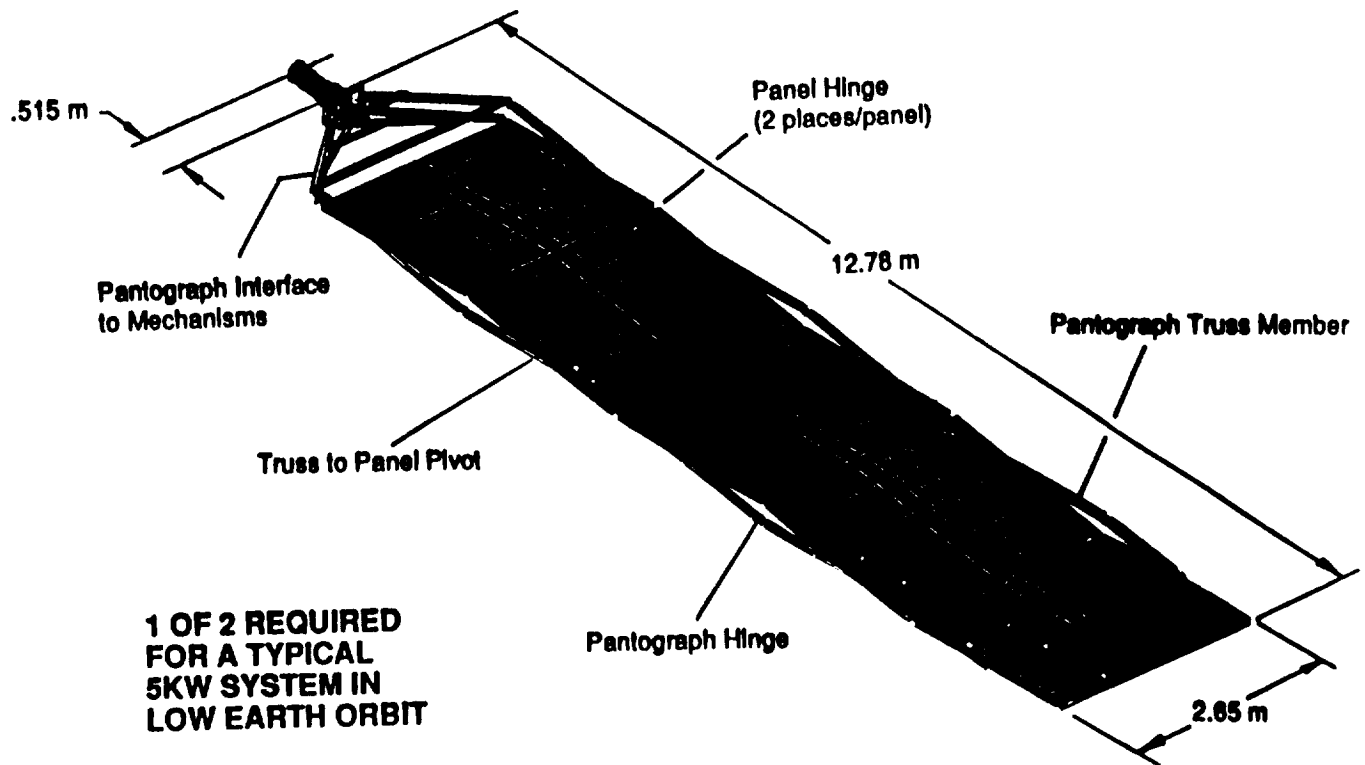
Mechanisms

- 2-Axis Array
- Array Defocus
- Array Deploy/Retract
- Slip Ring Power Transfer
- Launch Retention

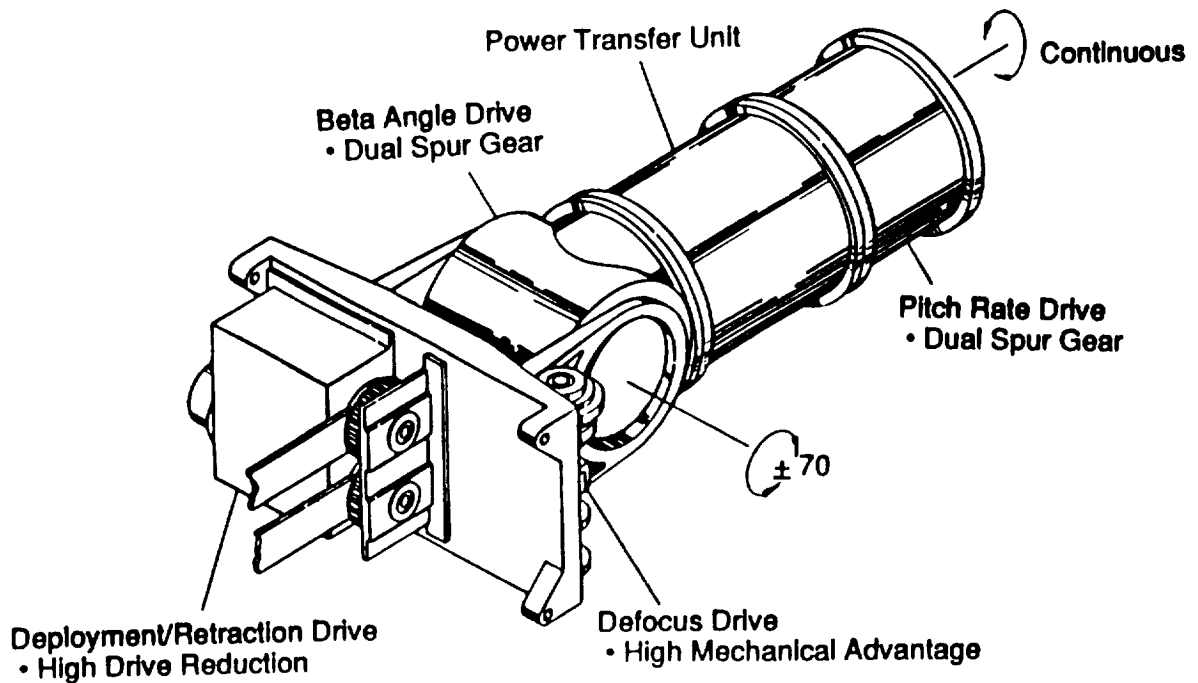
CONCENTRATOR ELEMENT DESIGN



SOLAR ARRAY



MECHANISMS

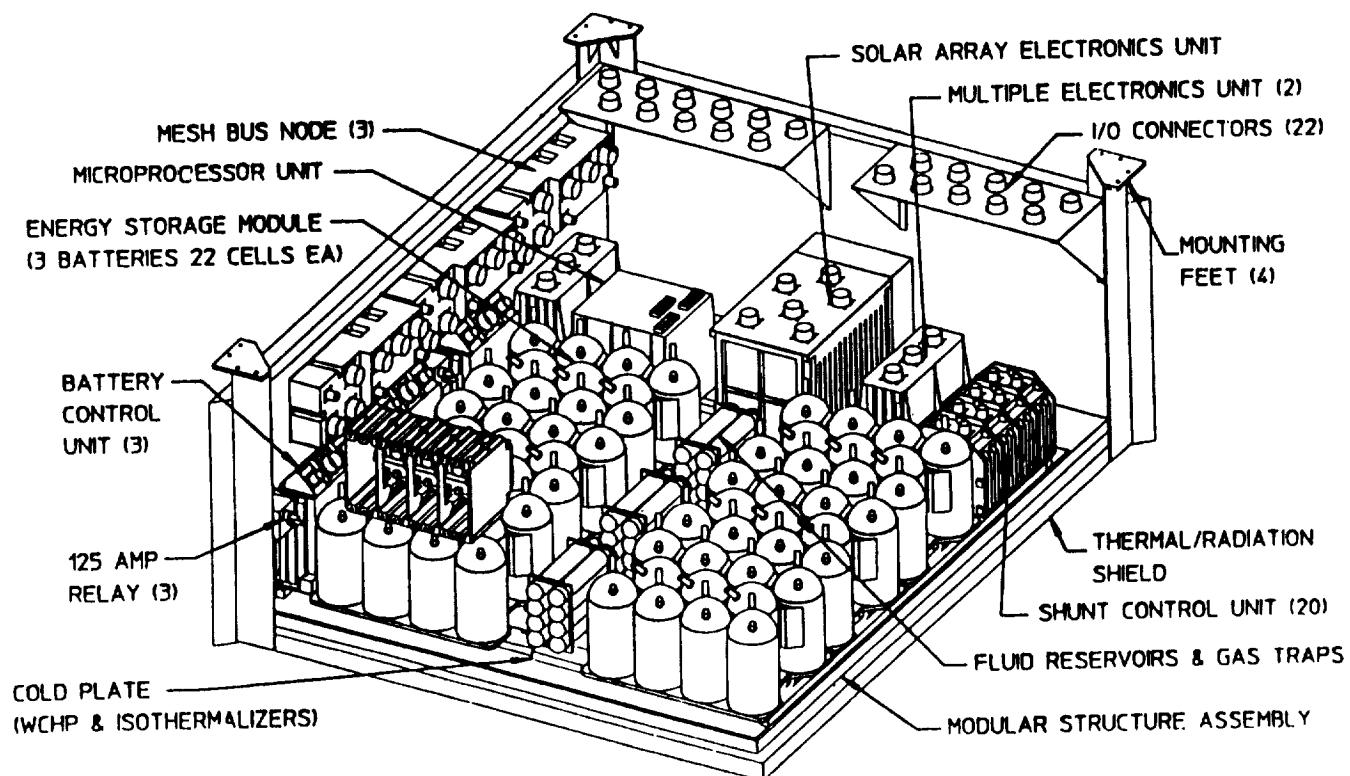


POWER MANAGEMENT AND DISTRIBUTION - OVERVIEW

KEY FEATURES

- **PROVIDES 100% UNINTERRUPTED POWER DURING AND AFTER THREATS OR SINGLE FAULTS**
- **UTILIZES A SHUNT CONTROL DIRECT ENERGY TRANSFER SYSTEM**
- **POWER BUS VOLTAGE 28 VDC (+ 6 VDC, - 4 VDC)
(HIGH VOLTAGE CAPABILITY WITH SIMPLE REVISED CIRCUITRY)**
- **PROVIDES INDIVIDUAL BATTERY CHARGE CONTROL TO EXTEND BATTERY LIFE**
- **USES A STANDARD 1553B REDUNDANT COMMUNICATION BUS AND ADA SOFTWARE**
- **CONTROLS FOR AUTONOMOUS SOLAR ARRAY TRACKING AND POINTING**
- **INTEGRAL THERMAL MANAGEMENT**

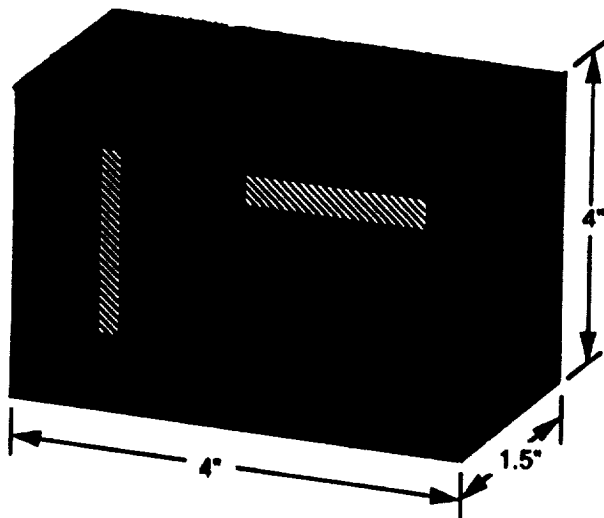
TYPICAL MODULAR POWER ASSEMBLY



RADIATOR NOT SHOWN
TOTAL QUANTITIES MAY NOT BE SHOWN FOR CLARITY

SUN SENSOR DESIGN

2-AXIS ANALOG SUN SENSOR



 INSULATION OVER AL HOUSING

 OPTICAL

OPTICAL PATH



LASER FILTER
SUBSTRATE
UV BLOCKING FILTER

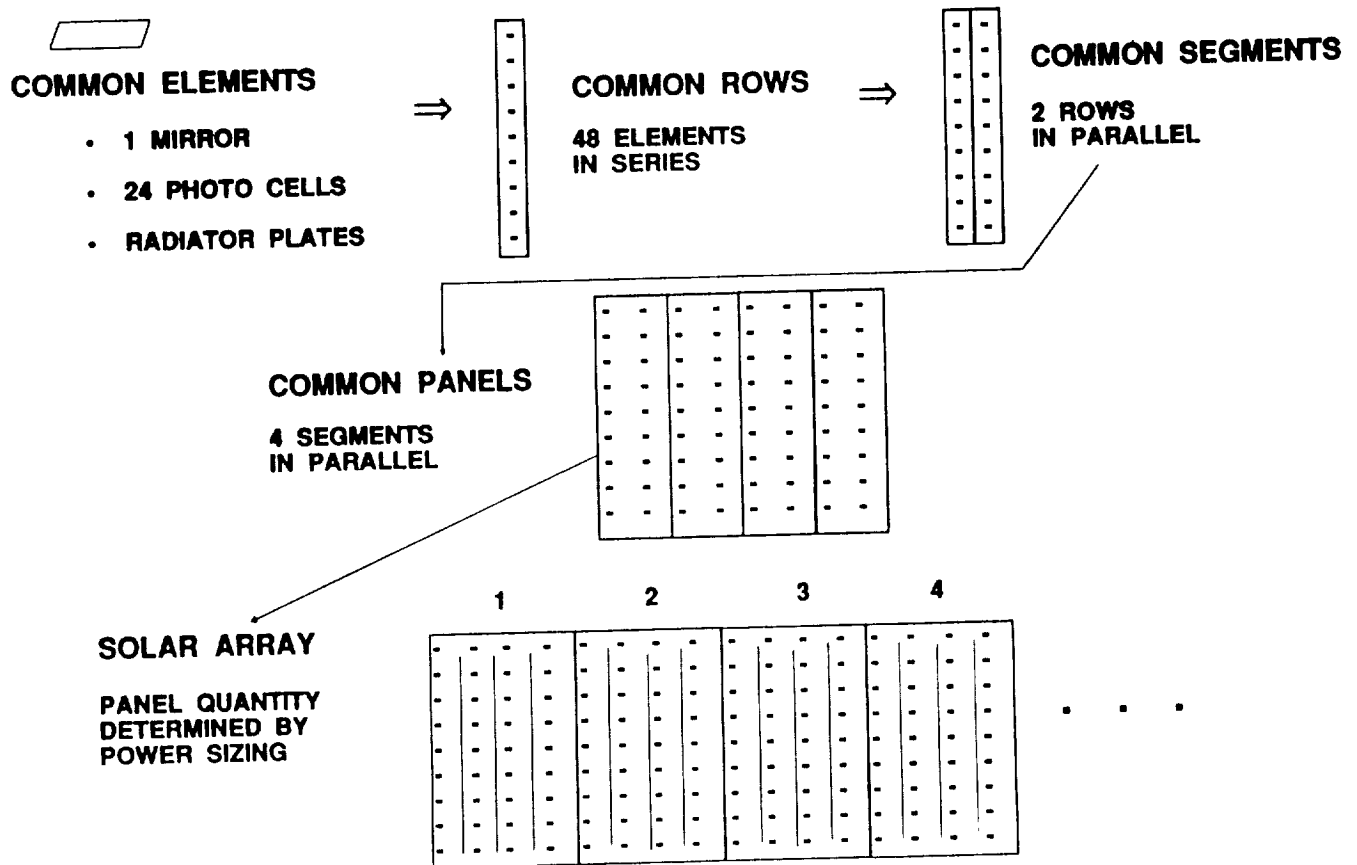


CR/SIOX MULTILAYER WITH SLIT
SIO₂
CR/SIOX MULTILAYER WITH CODE



PHOTO CELL
PRINTED CIRCUIT EPOXY SUBSTRATE
AL REAR COVER

MODULARITY: SOLAR PANELS



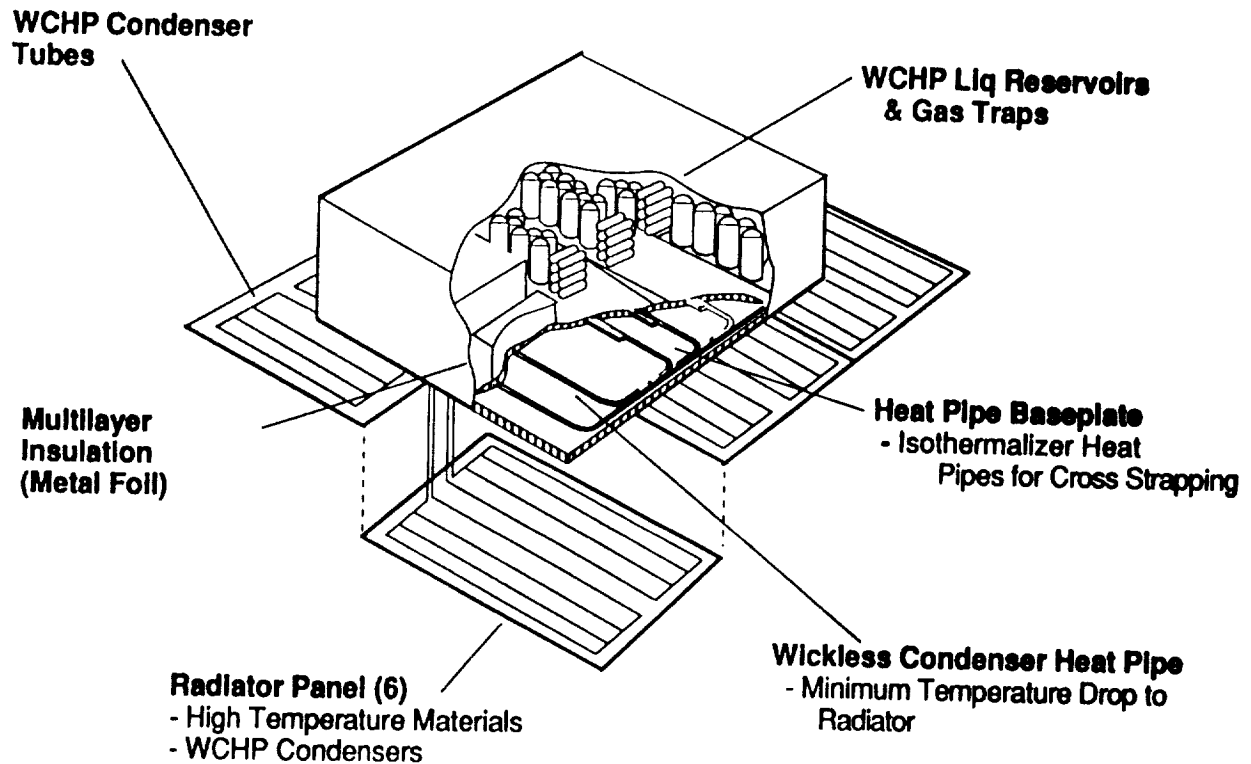
SUPER SURVIVABILITY

REQUIRES HARDNESS & ABILITY TO WITHSTAND ACTIVE COUNTER MEASURES

AS WELL AS THE NATURAL ENVIRONMENT

- ORBITAL DEBRIS
- ATOMIC OXYGEN
- VAN ALLEN BELTS
- SOLAR ACTIVITY

MPA THERMAL MANAGEMENT FEATURES



SURVIVABILITY YIELDS DURABILITY

**SUPER'S SURVIVABILITY BENEFITS USERS WHO DON'T DEAL
WITH HOSTILE THREATS**

- **SURVIVABILITY FEATURES PROVIDE ROBUST DURABILITY
AGAINST DEGRADATION FROM NATURAL ENVIRONMENT**
- **LESS THAN 1/3 THE DEGRADATION RATE OF A
CONVENTIONAL PLANAR ARRAY**

LOW POWER INITIATIVE

- WHY

- LOGICAL EXTENSION OF WORK ALREADY DONE**
- SIGNIFICANTLY MORE POTENTIAL USERS AT LOWER POWER LEVELS**
 - 0.5KW - 3KW INSTEAD OF 2 - 40 KW**
- DEMONSTRATE COMPATIBILITY WITH LATEST SDI ARCHITECTURE**
- IMPROVED FLIGHT DEMO OPPORTUNITIES → P91-B**

PHASES III & IV

PHASE III

- CRITICAL DESIGN (CRITICAL DESIGN REVIEW NOV 92)**
- FABRICATION (START MAY 92)**
- TEST & QUALIFICATION (COMPLETION 2ND QUARTER FY94)**
- DELIVERY OF FLIGHT HARDWARE (3RD QUARTER FY94)**

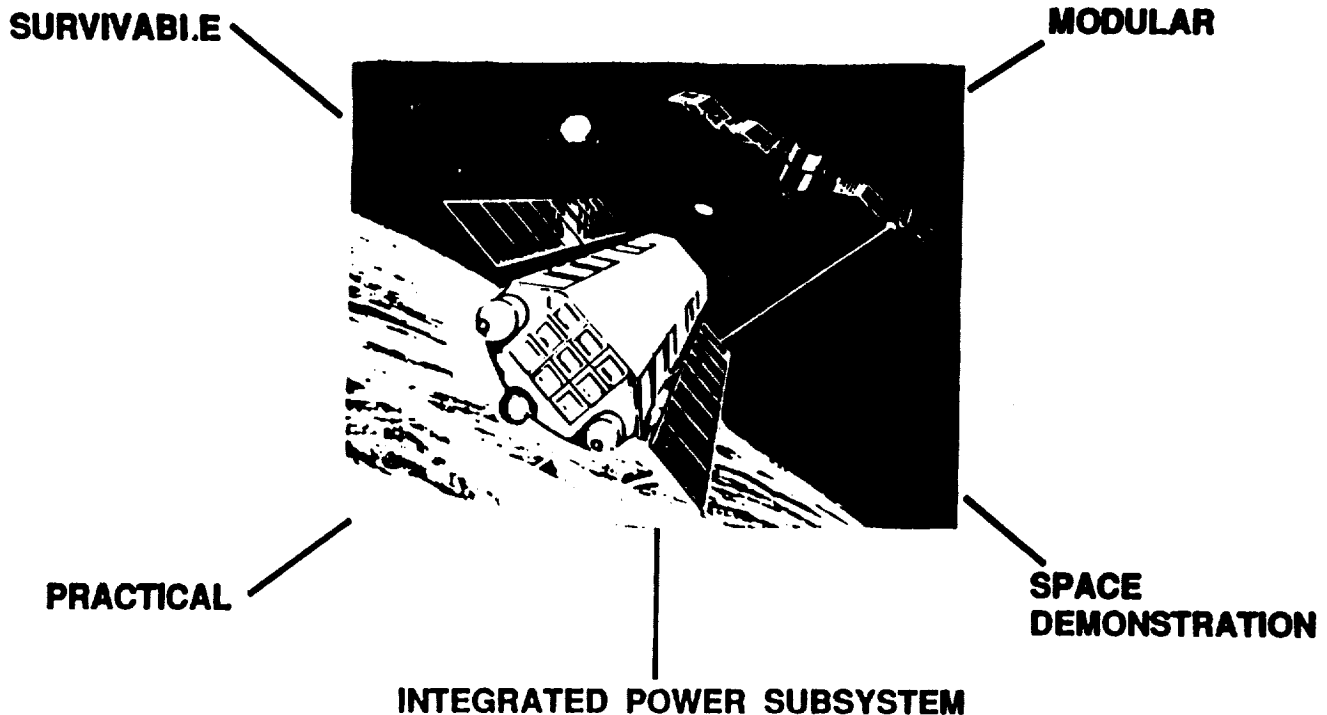
PHASE IV

- SUPPORT FOR SPACECRAFT INTEGRATION**
- LAUNCH SUPPORT (LAUNCH 4TH QUARTER FY95)**
- SUPPORT FOR ON-ORBIT OPERATIONS (3 YEARS)**

CONCLUSION

- **SUPER PROGRAM DEMONSTRATES A PRACTICAL GENERIC INTEGRATED SURVIVABLE (DURABLE) POWER SYSTEM**
- **QUALIFIED SUPER COMPONENTS AND ASSEMBLIES WILL BE AVAILABLE FOR USERS WHO DON'T NEED A TOTAL INTEGRATED POWER SUBSYSTEM**

SUPER



OVERVIEW

AIR FORCE AND SDIO

PHOTOVOLTAICS

**Lt. WILLIAM T. COOLEY
WL/POOC-2
WRIGHT-PATTERSON AFB, OH
PH: (513) 255-6235**

OUTLINE

- **INTRODUCTORY REMARKS**
- **BACKGROUND...STATE OF THE ART**
- **NEW START OBJECTIVES**
- **POSSIBLE TECHNOLOGIES (NO CONTRACTS YET)**
- **OTHER ONGOING WORK**

AIR FORCE/SDIO PHOTOVOLTAICS INTRODUCTORY REMARKS

- SDI ARCHITECTURE
 - NEW SYSTEMS
 - NEW PHILOSOPHY
 - TECHNOLOGY IMPLICATIONS
- PHOTOVOLTAICS PROGRAM DRAMATICALLY REDUCED
 - CONTRACT TERMINATIONS
 - NEW PHILOSOPHY TO MEET NEEDS

STATE OF THE ART PHOTOVOLTAICS

<u>CELL DESIGN</u>	<u>FEATURES</u>	<u>ACHIEVED BOL EFF %</u>	<u>CONTRACTOR</u>
GaAs/Ge	4 x 4cm 3.5 mil WA	18	ASEC
GaAs/Ge	4 x 4cm x 4.0 mil WT	18.5	SPECTROLAB
AlGaAs/GaAs	2 x 2cm x 8 mil (Rad Resistant)	18	RTI/ASEC
AlGaAs/GaAs	Single Junction	19	RTI/ASEC
AlGaAs/GaAs/InGaAs	3 Junction Concentrator	23 (100x)	VARIAN
GaAs	1 x 0.4 cm 8 mil	22 (15x)	SPECTROLAB
GaAs/Ge	2 Junction	24.0 (100x)	SPIRE
InP/GaInAsP	2 Junction on InP Substrate	15.0	ARIZONA STATE
GaAs + CuInSe	Mechanical Stack	23.1	BOEING

PROGRAM JUSTIFICATION TOP-LEVEL DIRECTION FOR SPACE

AF Puts Brakes On Upgrades To Space Systems

By VINCENT KIERNAN
Space News Staff Writer

WASHINGTON — Donald Rice, secretary of the U.S. Air Force, has approved a set of planning guidelines that call on the service to avoid costly improvements in its space systems, in an effort to cope with expected tight defense budgets and geopolitical shifts of the 1990s.

Rice has embraced the conclusions of a service-wide study, called the Space Investment Strategy, which mandates that the service slash the "cradle-to-grave" cost of its space systems, an Air Force official said. Also, it calls for placing increased emphasis on technological advances that could make military space systems cheaper to build and operate.

The study was conducted under the auspices of Richard McCormick, deputy assistant secretary of the Air Force for space plans and policy, but included representatives from throughout the service, including the Air Force Space Systems Division, Los Angeles, and Air Force Space

Command, Peterson Air Force Base, Colo.

Retired Gen. Larry Welch, former Air Force chief of staff, also approved the conclusions of the study before his recent retirement, said one Air Force official involved in the project.

The study builds on an earlier review of Air Force space efforts, called the Space Road Map, the official said. The intent was to produce a set of principles to guide the Air Force's budgetary decisions, but those studies did not make detailed recommendations about specific programs, he said. The effort's conclusions were presented in a series of briefings; no written report was produced, the official said.

"These reviews have led to a much crisper acquisition strategy for Air Force space efforts as we move into the 21st century," said Martin Fago, U.S. assistant secretary of the Air Force for space.

However, despite the study's conclusion that fiscal restraint will be required in military space programs, the Air Force and U.S. Defense Department clearly an-

See AIR FORCE, Page 20

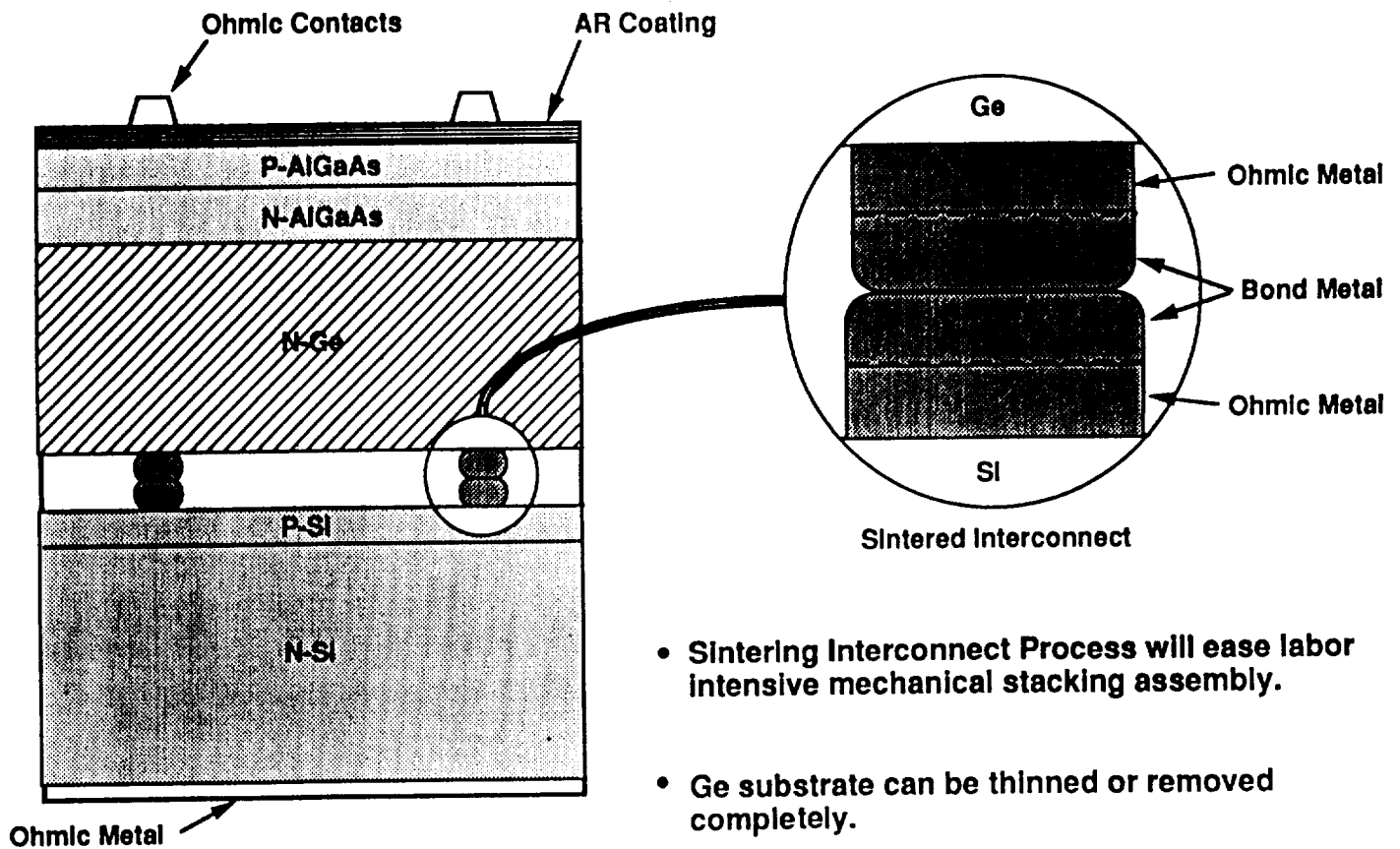
- SPACE NEWS, 13-19 AUGUST 1990
- DONALD RICE, SECRETARY OF AF APPROVES "SPACE INVESTMENT STRATEGY"
- ...SLASH "CRADLE-TO-GRAVE" COSTS
-"INCREASED EMPHASIS ON TECHNOLOGICAL ADVANCES THAT COULD MAKE MILITARY SPACE SYSTEMS CHEAPER TO BUILD AND OPERATE"

FY91 NEW START PHOTOVOLTAIC OBJECTIVES

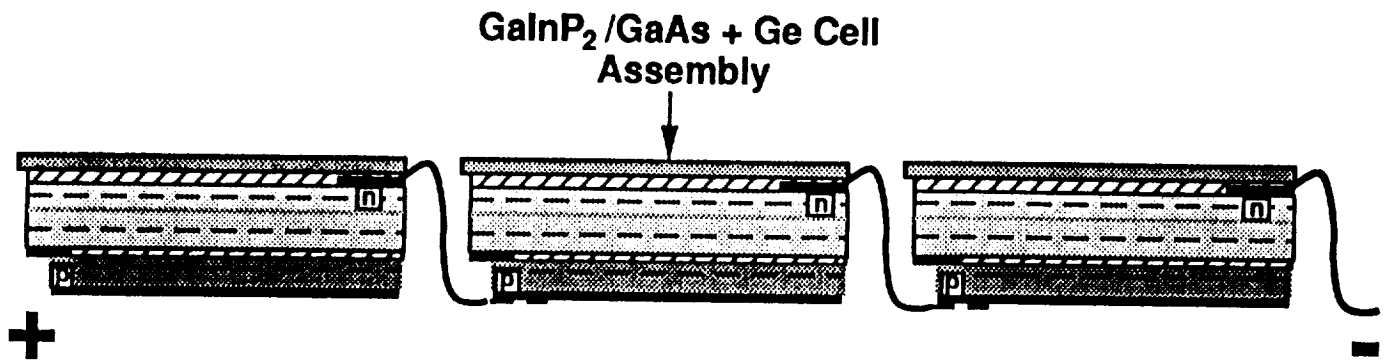
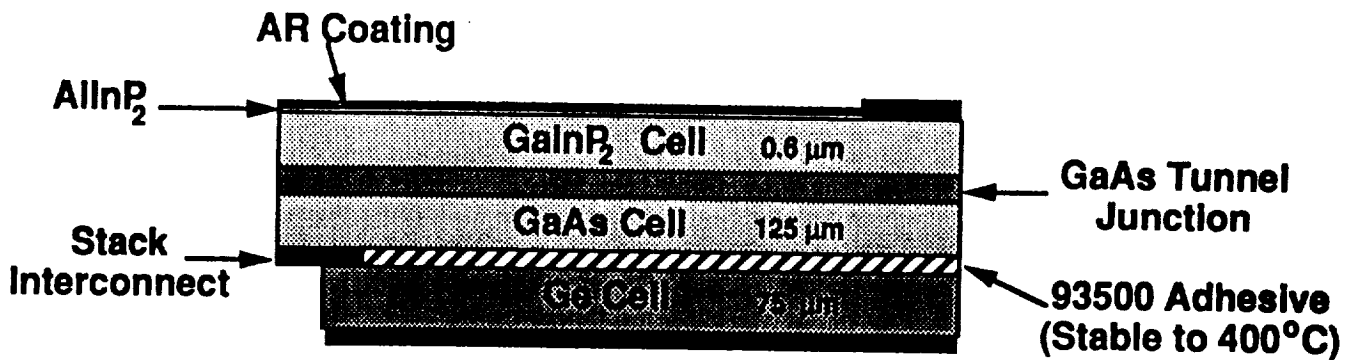
- **PER PRDA NO 91-01-PKRN**

- **MINIMUM 23 PERCENT EFFICIENCY WITH GOAL OF 30 PERCENT**
- **MINIMIZE COST (MEASURED IN \$/WATT AT EOL)**
- **LOW RADIATION DEGRADATION**
- **NEGLIGIBLE DEGRADATION WHEN SUBJECTED TO HIGH
TEMPFRATURES**
- **MODULAR SPECIFIC POWER > 80 W/Kg FOR DEFINED SUBSTRATE**
- **EASY INTEGRATION INTO CURRENT PLANAR ARRAY
CONFIGURATIONS**

AlGaAs (or GaInAsP) on Si MECHANICAL STACK CONFIGURATION



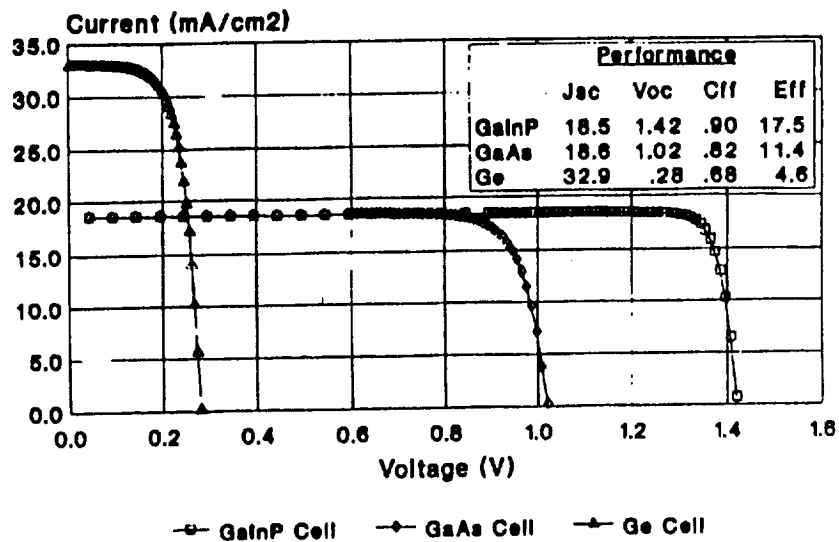
GaInP₂ /GaAs+Ge CONFIGURATION



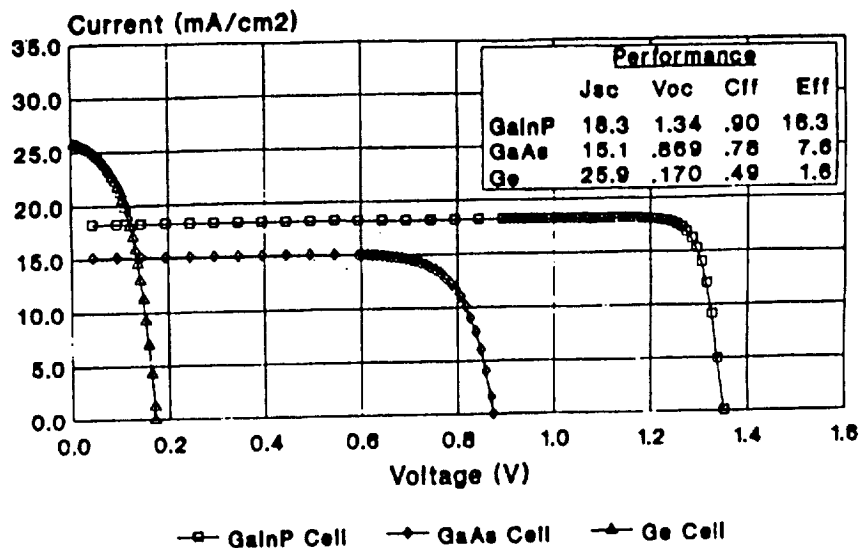
- 2 TERMINAL DEVICE
- "PLUG IN" TO EXISTING ARRAY CONFIGURATIONS

GaInP/GaAs+Ge

I-V CHARACTERISTICS



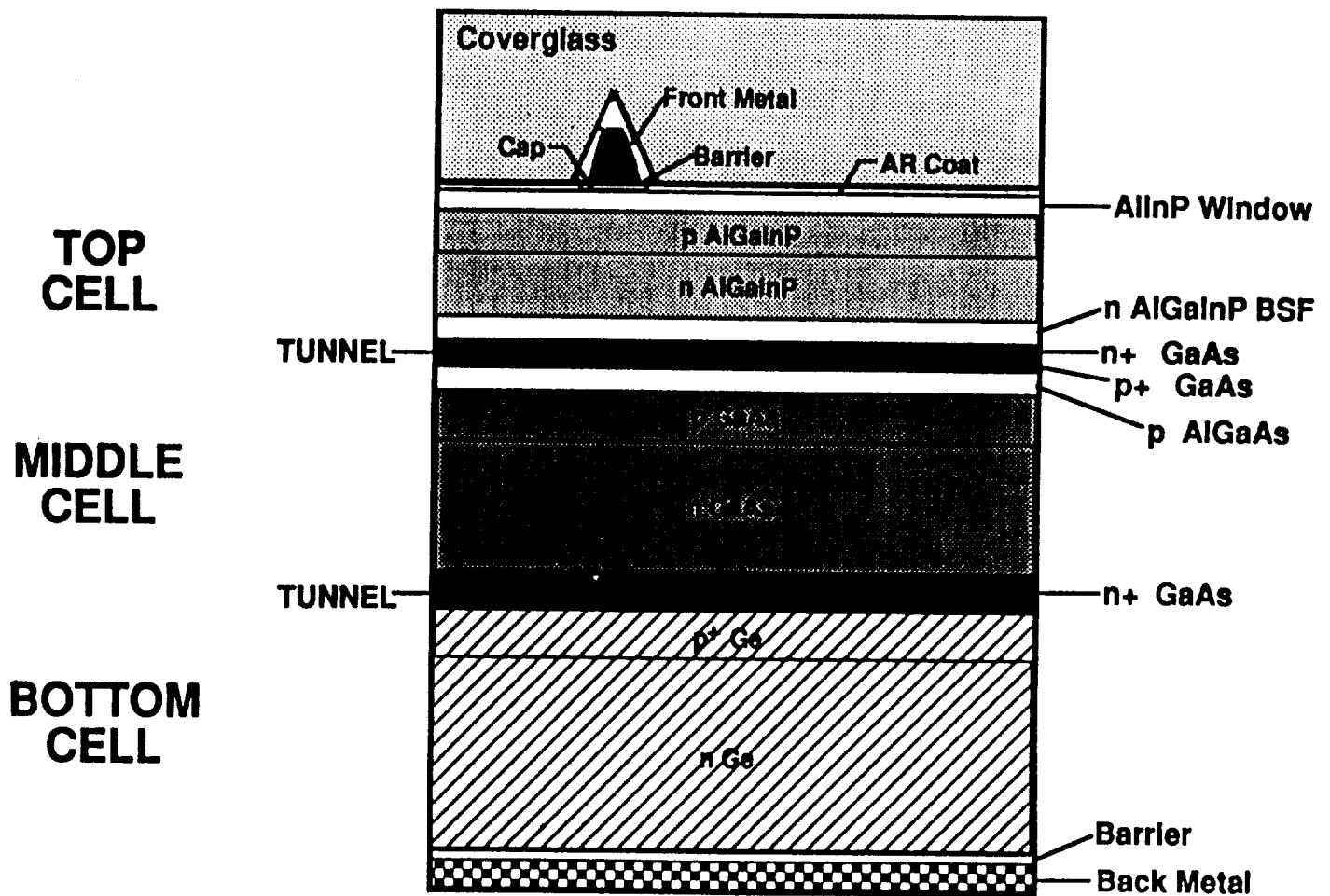
BOL



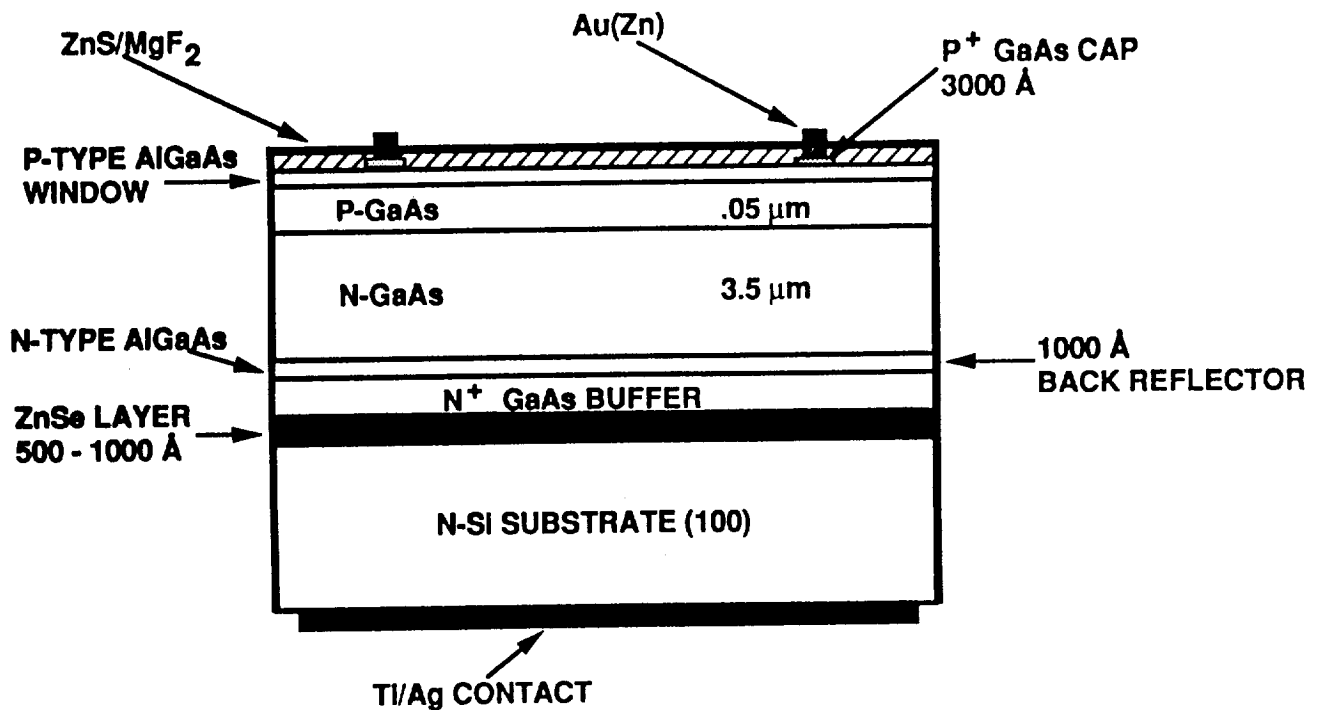
EOL

10^{15} 1MeV electrons/cm²

AlGaInP/GaAs/Ge MONOLITHIC CONFIGURATION



GaAs/ZnSe/Si CONFIGURATION



- ZnSe LATTICE MATCHED TO WITHIN 0.24% OF GaAs
- LOW DEFECT SINGLE CRYSTAL ZnSe HAS BEEN GROWN ON Si



National Aeronautics and
Space Administration

Report Documentation Page

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15. Supplementary Notes Responsible person, Dennis Flood, Lewis Research Center, (216) 433-2303.					
16. Abstract <p>The Eleventh Space Photovoltaic Research and Technology conference was held at NASA Lewis Research Center from May 7 to 9, 1991. The papers and workshop summaries presented in this volume report remarkable progress on a wide variety of approaches in space photovoltaics, for both near and far term applications. Papers were presented in a variety of technical areas, including multijunction cell technology, GaAs and InP cells, system studies, cell and array development, and photovoltaics for conversion of laser radiation. Three workshops were held to discuss the following topics:</p> <ul style="list-style-type: none">• Thin Film Cell Development• III-V Cell Development• Space Environmental Effects					
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